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THE SHOCK AND VIBRATION DIGEST. VOLUME 11. NUMBER 9,(U)
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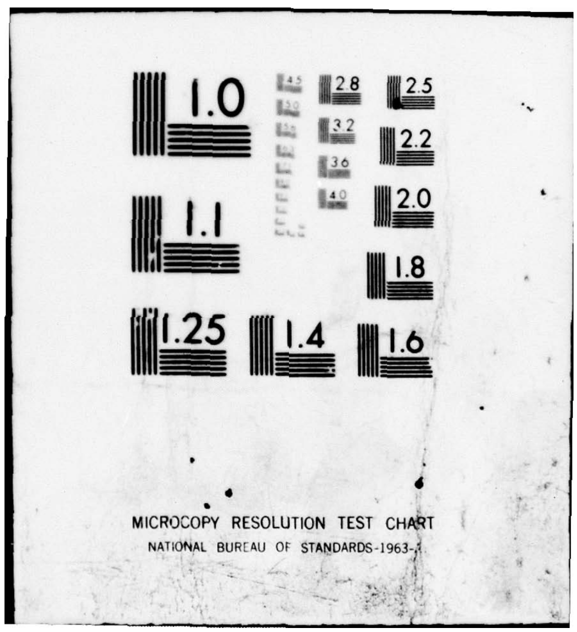
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SVIC NOTES

The Shock and Vibration Information Center (SVIC) had its humble beginning at a meeting held on 7 January 1947 at the Naval Research Laboratory. This meeting, usually referred to as the First Shock and Vibration Symposium, was really a planning session at which the objectives and method of operation of what has become SVIC were formulated. The names of some of those in attendance at that meeting read like a Who's Who in shock and vibration - Dr. Elias Klein, Dr. Irwin Vigness, Dr. Horace Trent, Mr. E.F. Noonan, and Mr. Harry Rich - to name a few. Although there has been considerable expansion, the wisdom provided by these and other persons in attendance at that 1947 meeting established a mission for SVIC which remains largely valid today. The only major change was to expand the community to be served beyond that of the Navy.

Today, SVIC is one of several discipline-oriented DoD information analysis centers (IACS). SVIC, like each of the other IACs, had to develop its own method of operation tailored to the nature of the discipline covered and to the population of the technical community which it serves. In general each center must in its own way collect, review, digest, analyze, appraise, summarize, disseminate and provide advisory and other user services concerning the available scientific and technical information and data in a well-defined, specialized field. IACs must deal in information instead of merely documents. The key word in describing the general mission of an IAC is "analysis". It is in this light that IACs have been recognized as effective mechanisms for improving the processing and usefulness of technical information. This is a result of the realization that the individual scientist or engineer cannot keep up with new developments in his field, or even be aware of them, by his own unaided efforts and still be able to make some original contributions to the technology himself. He must rely on competent colleagues who find professional satisfaction and stimulation through review and analysis. It is these "colleagues" who make up the staff of a successful IAC like SVIC.

Every project involving the development of machines, vehicles or structures must make use of shock and vibration technology. A broader term is dynamics. The dynamic environments affect the successful design of any system where motion or noise is involved. It is in this sense, the broad and varied application of a particular technology, that SVIC defines its scope.

As a first example, consider the general category of machines. The moving parts produce vibrations which affect the life of the components. The vibration produces noise which affects the human operator. Machinery vibration may affect the structure in which it is located or may be affected by vibrations from that structure or by shocks generated by seismic disturbances. The possible effects on performance and life are almost endless.

Vehicles, whether they be for land, sea, air or space, are affected by the vibration and shock induced by the medium over or through which they travel and by the dynamic environments produced by their own propulsion systems. All systems aboard must withstand these effects. If there are human occupants, they must also survive and function.

Finally, even fixed structures such as bridges, dams, buildings and power plants must withstand seismically-induced shock and other ground motions. Hardened structures are specifically designed to survive nuclear-induced ground shock.

To give boundaries to the technology covered by SVIC, consider the various phases in the research, development, test and evaluation of any system. The nature of the full life mission of the system must be established so that the criteria for its design and development can be defined. To do this the environments must be assessed, the performance specifications written, methods of analysis and design selected and applied, computer programs selected or written, materials of construction evaluated, components isolated or protected, the system tested, its response measured and the measured data analyzed. It is in all these areas that SVIC collects, reviews, analyzes and disseminates the information generated by the evolving technology.

This issue of the DIGEST is in commemoration of our 50th Shock and Vibration Symposium. In my opinion the technical program is outstanding, including some very distinguished invited speakers, both from the United States and abroad. In honoring this occasion we have reprinted herein the earliest article on the Navy shock machines by the late R.H. Oliver. We are favored with a history of full-scale ship shock testing by Robert Bort of NRL who, at our request, contributed his personal time to prepare the article. We hope that these and other features will make this issue even more interesting than usual. And - may the next 50 symposia be even more productive than those already held.

H.C.P.

EDITORS RATTLE SPACE

The Future: Shock and Vibration Technology

As we approach the 50th Shock and Vibration Symposium, we must marvel at the advances in shock and vibration technology in the last 20 years. Two questions arise on the occasion of this important anniversary: what was the basic ingredient behind the development of shock and vibration technology? And what factors will influence further development? The answers to both are simple -- electronics.

The development of practical electronic instrumentation has made it possible for the experimenter to analyze complex vibration signals and diagnose machine and structural faults. Before the development of wave analyzers and real time analyzers, it was impractical to analyze vibration records. (They could be digitized and analyzed by Fourier analysis but only at considerable expense.) For the engineering analyst the digital computer has made computation of the vibratory behavior of a complex system a reality.

Certain stages in the modeling of physical phenomena still lag computational capacity and techniques, but real engineering can be performed with the aid of the computer. Most recent research efforts seem to have been aimed at developing computational techniques. Such physical data as damping values, which are required to adequately model machines and vehicles, are not yet available. However, data are available for certain specialized components -- vibration control devices and fluid-film bearings. Without good data on all dynamic physical processes the art and science of modeling will not progress beyond the present technology. This means that simulation of the dynamic physical behavior of systems will evolve no further. Fortunately, the spin-off from good experimental studies will provide some of these data. Unfortunately, no one is willing to pay for the basic modeling studies necessary to develop data for physical characterization of components and systems. It is to be hoped that this trend will change in the future.

In the area of measurement small advances will be made – especially in analysis and interpretation of vibration data. The techniques of experimental modal analysis -- the use of calibrated force gages and real time analyzers in conjunction with mini-computers -- will yield data not only for the solution of field problems but also for characterization of materials, components, and systems. And these data will make computer simulation a reality. Good data analysis will add to the already-developing techniques of analysis – orbital display, Nyquist plotting, and sum and difference frequency display. Instant fault identification will become a reality.

The major developments in shock and vibration technology will depend on the successful combination of engineering computer simulation and experimental data analysis. Experiment and computation to date have been utilized only rarely as a unit; for instance, in flexible rotor balancing. Experiment and computation will be used to analyze machines, vehicles, and structures. A computer model will simulate the dynamic behavior of a system, and measurement and analysis of vibratory systems will provide feedback capability. Fault diagnosis and correction will thus become less of an engineering art and more of an engineering science.

The technology for the solution of vibration problems will be strengthened, but the problems and challenges for the engineer will increase: lightweight, high performance, energy efficient, noiseless, and vibrationless systems will create new challenges.

R.L.E.

REPRINTED FROM

SHOCK AND VIBRATION BULLETIN

Shock and Vibration Bulletin No. 3
May 1947

THE HISTORY AND DEVELOPMENT OF THE HIGH-IMPACT SHOCK-TESTING MACHINE FOR LIGHTWEIGHT EQUIPMENT

R. H. Oliver BuShips

Until such time as our committee on definitions comes forth with a suitable definition of the term *shock*, I am forced to refer to shock in the same loose vein as in the past. On this basis, shock has been generally thought of as that phenomenon which is characterized by the rapid initial displacement of a foundation or structure, followed by a violent, transient, decaying vibration of the foundation or structure at its own natural frequency or frequencies of vibration. In the event that the shock is not confined to a single pulse, but has several pulses, as is the case with underwater explosions at considerable depth, the initial displacement may be amplified in the succeeding violent vibration or may be nullified, depending on the shock pulse frequency, the natural frequency of vibration of the foundation or structure, and the phase relationship between them.

At the close of World War I, and even up to the early part of the year 1939, the major causes of shock to equipment aboard vessels of the U. S. Navy were

considered to be impacts from enemy shells and torpedoes and the firing of the ship's own armament. At that time it was generally conceived that nothing much could be done about equipment which was subject to shock from enemy causes other than to avoid, if possible, the mounting of equipment directly on armor plating.

Insofar as shock to equipment caused by firing the ship's own armament was concerned, it was generally agreed that equipment mounted in the main-battery turrets, broadside-gun compartments, and the like needed to be more ruggedly constructed. Requirements for ruggedness of reduced magnitude were also found to be necessary in other portions of the ships which were observed to transmit shocks to equipment. In order to be able to test equipment for these various requirements, the shock-testing machine, now commonly known as the 150- or 250-foot-pound machine, was devised and constructed shortly after the close of World War I. The machine was so arranged as to test for the requirements of 25, 50, 150, and later 250 foot-pounds, which were imposed on equipments for various locations in the ships. Equipment passing these tests was considered satisfactory for installation aboard ship.

The deficiencies of cast iron and other brittle materials for use in equipments aboard ship were recognized, and, insofar as possible, steps were taken in the late 1930's to eliminate their use for strength members of equipment, especially the use of cast iron in end bells on motors and generators. This was the only major change made in design to evolve equipment which was more resistant to shock.

The early stages of World War II brought great changes in the problem of protecting equipment from shock aboard ship. Influence mines, containing large charges of explosive, and large aerial bombs were being used. It was found through bitter experience that near-miss aerial bombs exploding below the water surface and non-contact explosions of mines were giving the ship as a whole a terrific shaking without necessarily causing major hull damage. Equipment mounted on decks and bulkheads disintegrated; heavy machinery items came adrift because of failure of the mounting feet; piping and ventilation systems throughout the ship were demolished. The need for better equipment and mounting methods was imperative.

As a method of approach to solving the problems involved, the British designed a machine in 1939 which is very similar to our present machine for testing lightweight equipment. It was believed that the shocks administered by this machine were closely similar to those encountered aboard ship, because damage inflicted on equipment tested on the machine was very similar to that observed on identical units of equipment mounted aboard ship.

Late in 1940, the General Electric Company manufactured one machine from British sketches for use in this country. After considerable experimental testing was performed on this machine, it was considered that it would be an invaluable aid to our Navy in the design of shock-proof equipment. Accordingly, a contract was entered into with General Electric to furnish machines for use in the Navy Yards in New York, Portsmouth, and Washington, and at the Naval Research Laboratory. By late 1942, several private concerns, including General Electric, Westinghouse, ITE, Cutler-Hammer, Allis-Chalmers, Ward Leonard, and the Arma Corporation had arrived at the conclusion that a machine in their own plants was indispensible. Machines were purchased and put in operation in the plants of these various manufacturers.

Also late in 1942, a group of 16 manufacturing concerns in the Chicago area had realized the necessity of a machine for their use. Consequently these 16 firms put up sufficient funds to purchase one machine, which was installed at the Armour Research Laboratories in Chicago. It was considered advisable to establish the machine at Armour to preclude the possibility of of one manufacturer's being required to test the products of other manufacturers. The Armour machine was completed and ready to conduct tests by mid-March of 1943.

The list of lightweight machines available for test purposes grew in this manner until, at the end of the War, a total of 25 were in operation. Of this total, eight machines were maintained in government laboratories.

In order to simulate on the shock-testing machine the various types of equipment-mounting conditions encountered aboard ship, a series of adapter plates for the machine were designed. The simple flat plate mounted out from the face of the anvil plate on car-building channels was thought to reproduce closely the action encountered by equipment mounted on bulkheads. A similar flat plate with a bracket or shelf protruding at right angles was constructed for equipment which is normally mounted on light decks or on brackets supported by bulkhead stiffeners. Other types of adapters were designed to provide mountings for switchboard instruments and the like, which were quite similar to the types of mountings found aboard ship for these particular equipments. It is to be kept in mind that all of these adapters were designed for testing equipment whose weight was not in excess of approximately 250 pounds.

The continued operation of these machines brought to light several deficiencies in their design. The first major trouble encountered was mechanical failure of the anvil plate after a considerable number of blows had been administered. The stiffeners on the backs of the plates broke, and failure of the intermittent weld holding the stiffeners was encountered. As a result of these failures, the anvil plates dished and warped. Consequently the anvil plates were redesigned using 13.8-pound H-beams for stiffeners in place of the original T-beams, and continuous fillet welding was employed. In addition, an extra plate was introduced between the striking pad for the back blow and the H-beam structure, to allow better stress distribution.

These changes in the design of the anvil plate resulted in a great improvement in the useful life of the plate. However, it was soon necessary to change again the design of the plates to conform with the rulings of the War Production Board. The Board deleted the 13.8-pound H-beams from the list of shapes to be rolled, so redesign was effected to incorporate the use of 13.0-pound H-beams. For the sake of uniformity among machines, all owners were requested to install anvil plates incorporating the lighter beams for stiffeners late in 1943.

Considerable trouble was also experienced in the maintenance of the bearings on the swinging hammer for back blows. The bushings were wearing to an oval shape in short order, and this wear caused the hammer velocity to be erratic. In addition, the arms supporting the hammer were not sufficiently rigid, and allowed the hammer to wobble so that the striking pad of the anvil plate was not struck squarely. These difficulties were overcome by stiffening the arms and installing longer bushings at the pivot points.

A series of high-speed movie shots were taken of one of the unmodified

machines at the Naval Research Laboratory. This film shows quite plainly the action of the machine at the instant of impact for all three directions of hammer blow. It shows considerable rocking of the dropping hammer due to the flat contact surface of the hammer and the considerable amount of looseness in the hammer-guide tracks. Furthermore, by observing closely, it can be seen that the anvil plate does not return to its original position after the blow is administered.

It is apparent from this film that the shock administered to equipment mounted for test on the machine is of a very complex nature. This is in definite contrast to the type of shock administered by the various machines which were viewed at NOL. These machines imparted shocks of a very simple nature, such as a sine-wave pulse, a square wave, and the like. The shocks encountered by equipment aboard ship are of a complex nature, and the HI shock machine intentionally imparts a complicated shock motion to equipment.

Very early in 1943, as the number of these machines in operation increased, it became apparent that there were numerous discrepancies between the various machines, which affected the nature and intensity of the shocks administered. The fact that equipment which had passed all developmental testing on a manufacturer's machine sometimes failed to pass the acceptance tests on a government-owned machine particularly indicated the existence of these discrepancies. Furthermore, it was readily apparent that the intensity of the shocks was not identical in all three directions of blow on any of the machines.

Consequently, in May of 1943, a broad program was authorized to investigate the operating characteristics of all machines for the purpose of standardization, so that the severity of test would be identical for all three directions of blow, and would be the same on all the machines. The revolving-drum type of displacement recorder was considered at that time to give the most faithful reproduction of the action of the machines, in addition to being one of the most simple of the available instruments to operate. The action of a considerable number of the machines was investigated and recorded for all directions of blow, and for several intensities of blow with various loads on the 4A adapter plate.

Comparison and analysis of all these records led to a series of modifications which were effected on one of the machines at the Naval Research Laboratory. Extensive tests were made on the modified machine, and the records taken were compared with those which had been taken previously on the other machines. It was considered that, as a result of these modifications, the severity of test was closely the same in all three directions, and that the nature of the modifications would assure close similarity of test on all machines. Conclusions and recommendations regarding the modifications were put out in report form by the Naval Research Laboratory late in 1945.

The major changes to be made were:

1. Installation of hammers having approximately spherical contact surfaces.
2. Replacement of the swinging-hammer arms by new ones which had more rigidity and greater width of suspension, to eliminate wobbling of the hammer laterally as it falls.
3. Replacement of the lorry springs beneath the anvil plate by coil springs having stops to limit the travel to 1½ inches.
4. Installation of positive stops on the springs retarding the motion of the anvil plate under the action of back and side blows. These stops limit the travel to 1½ inches.

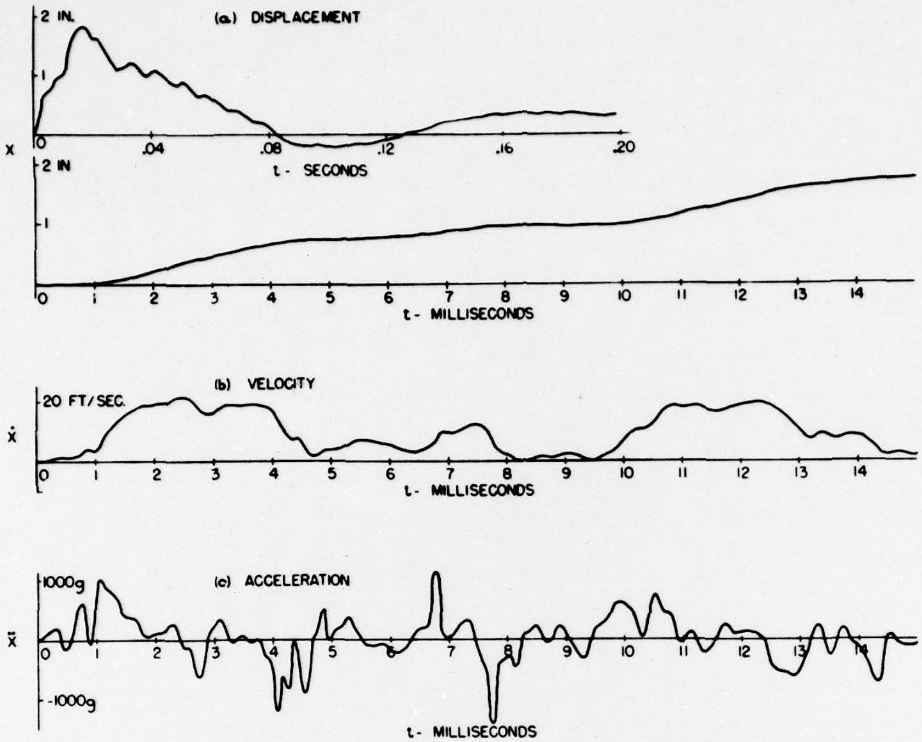

FIG. 1. Characteristic curves for HI Shock Machine

In the summer of last year, modification of all government-owned machines to these standards was authorized, and all private owners were requested to effect the modifications on their machines. In order to test equipment ordered on contracts dated prior to this authorization, it was considered advisable to retain one unmodified machine at the Material Laboratory in the Naval Shipyard in Brooklyn. At such time as these contracts are completed, this one machine will also be modified.

The machines are in the process of being modified at the present time. In the letter of authorization for modification of government-owned machines, it was requested that the machines be modified and ready for test by 1 December of last year. However, Bureau records indicate that the only machine which has been completed to date is the one at the Material Laboratory, Brooklyn, N.Y.

Figure 1 shows typical curves of the action of the center of an unloaded 4A plate caused by a five-foot back blow. The displacement curve was recorded by a rotating drum type of displacement meter, and the velocity and acceleration curves were derived from it. These curves represent the action of the machine prior to the incorpation of the modifications previously mentioned.

A HISTORY OF SHOCK TESTING OF SHIPS WITH UNDERWATER EXPLOSIONS

R.L. Bort*

"If it works, don't fix it." - Johnny Bachman

When the Director of the Model Basin at Carenes, France, visited the United States in 1964 at the invitation of the Bureau of Ships and the David Taylor Model Basin, he was amazed. He found such a vast array of projects and researches being conducted by the U.S. Navy that it was difficult to find out exactly what was going on in any particular field. He wrote later that there seemed to be three independent organizations involved. "All three seem to act at the same level, all three are completely staffed, and all three cover the entire field each working independently."

His amazement soon gave way to admiration. "The officers and civilian personnel working in these separate organizations," he wrote, "give the impression of making, in reality, only a single task group. ... The main advantage which the Americans have over the French is their unlimited budget, vast numbers of personnel, and overlapping but cooperating organizations."

This view from outside shows both the strength and weakness of the U.S. Navy's approach to problems. It also illustrates the problem a historian faces in assembling a coherent account of progress in any particular field. There have been three major centers of work on shock testing of ships in the U.S.: the Underwater Explosions Research Division of the Norfolk Naval Shipyard at Portsmouth, Virginia; the David Taylor Model Basin at Carderock, Maryland; and the Naval Research Laboratory in Washington, D.C. Each center took on the entire problem of developing methods to assure that combat ships could operate under combat conditions despite mines, depth charges, near-miss bombs, or underwater nuclear explosions. Each center developed its methods independently and assembled full-service personnel teams to attack the problem in its own way. A proper history would have to be written by a committee capable of weighing the various approaches and providing a balanced account. The present history is a biased and personal one.

BEGINNINGS

"What is new is not true, and what is true is not new." - Richard J. Neuhaus

Submarine warfare and antisubmarine warfare were invented simultaneously in 1776 when David Bushnell's submarine, ***Turtle***, attempted to attach a keg of black gunpowder to the keel of H.M.S. ***Eagle***, the flagship of Admiral Howe's fleet. The attempt failed in its immediate objective but so frightened Howe that he immediately withdrew his fleet and his person from New York harbor. Causes of the failure are not clear. According to one account, it was found unexpectedly that the bottom of ***Eagle*** was sheathed in copper, so that the screw for attaching the charge could not be started. According to another account, neither Bushnell nor his brother, both of whom were skilled in operating ***Turtle***, were available at the last minute, and the submarine had to be operated by an unskilled replacement. As the replacement maneuvered toward ***Eagle*** (by turning a crank attached to a propeller), he surfaced (by pumping out the bilges) to get his bearings and was spotted by a lookout. The lookout raised a cry, and withdrawal seemed the most prudent course of action.

Napoleon, much taken with the prospect of eliminating enemy ships by blowing them up from beneath, financed a research and development project to explore the possibility. A duplicate of Robert Fulton's 1797 submarine ***Nautilus*** was built and equipped with a mechanism for attaching a charge

***Mr. Bort is an employee of the Naval Research Laboratory, but this article was prepared on his own time and his opinions are his own. They do not necessarily reflect the opinions of the Naval Research Laboratory or the Department of Defense.**

to the keel of a ship. Napoleon, always the pragmatist, insisted on a full-scale demonstration, and an old schooner was successfully blown up off the coast of Brest. It was possibly the first example of an underwater-explosion weapon that passed through the normal sequence of fundamental research, exploratory development, and design development, to acceptance by the fleet.

The Confederacy built midget submarines called "Davids" during the Civil War. One succeeded in sinking the Union ship ***Housatonic*** in 1864. In the same year, a Union ship sank the ironclad ***Albemarle***; an explosive charge was attached to a pole. The ship was maneuvered so that the pole was under the otherwise invulnerable ironclad, and the charge was detonated.

A government report published in 1881 by a Lt. Col. Henry L. Abbot of the U.S. Army Corps of Engineers described what was then known about the effects of "submarine mines" on ships. (The report was discovered by Dr. A.H. Keil of the Massachusetts Institute of Technology, who described some of its contents in an after-dinner speech at a workshop on weapons effects held in 1971. Dr. Keil is a leading expert in underwater explosions and has directed research programs at the Underwater Explosions Research Division of the Norfolk Naval Shipyard and the David Taylor Model Basin.)

In the government report, Lt. Col. Abbot summarized experiences from underwater-explosion tests conducted in the U.S., Great Britain, Sweden, Austria, Turkey, and Germany and included results of his own studies. His report contained the following remarkable description of what happens to a ship under attack, as quoted by Dr. Keil:

"A vessel in the vicinity of an explosion may be exposed to three distinct dangers: 1st, its hull, embedded in the aqueous cannon, may be ruptured by the initial shockwave transmitted from molecule to molecule through the fluid. Second, should the hull be situated near the vertical through the charge, its resistance may prove to be less than that of the superincumbent water; and the line of least resistance may thus be deflected from its normal direction, and traverse the vessel. Third, in the case of the enormous charges sometimes employed in submarine mining, the wave generated by the explosion may rack the vessel beyond its power of endurance, or by risking amidships may even break her in sunder."

In the harsher, jargon-filled language that is popular 98 years later, we would say that an explosion can produce hull rupture, shock damage, and whipping damage.

As Dr. Keil commented, "In the years up to World War II, we see a systematic expansion of Lt. Col. Abbot's approach of background research and developmental testing carried out by the naval architects and the weapon designers." Weapon designers worked to develop larger explosions and to deliver the charges more accurately. Naval architects countered with side protection systems, shock resistant equipment, and stronger hull girders.

The U.S. Navy began a regular program of testing its ships for resistance to underwater-explosion attack in 1941. The tests provided a direct means for evaluating and improving the performance of ships in combat. The procedure is simple but arduous: test a ship, find weak points by noting damaged components, and develop improvements to strengthen the weak points. The improvements must then be tested again for effectiveness before they are passed on for adoption in new construction or retrofits.

WORLD WAR II

"Seek simplicity and distrust it." - Alfred North Whitehead

Both the British and the Germans found themselves under the gun during World War II as a result of unexpected weaknesses in their ships during underwater-explosion attacks. German documents recovered after the war showed that the problems of the two navies were strikingly similar and that each arrived independently at the same general methods for solving them.

British problems were related to influence mines, which could so disrupt vital equipment on ships that they would be dead in the water as a result of shock from a mine not close enough to produce hull damage. The most pressing problem for the Germans was damage to equipment on submarines

as a result of Allied depth-charge attacks aided by the new technologies of radar and asdic. The problem was so severe that the initiation of a depth-charge was sometimes taken as a signal to surface the submarine immediately and rig it to sink after the crew escaped; an example is the U-505 on display at the Museum of Science and Industry in Chicago, Illinois.

The German Navy set up a shock-protection program the mainstay of which was the testing of several submarines with underwater explosions. Probably the first realistic measurements of what happens to the hull of a submarine during an underwater-explosion attack were made. It was assumed that the test measurements would allow design and construction of shock-simulating machines to produce shocks of proper severity for testing equipment. A simple device was built that drove steel spikes into lead blocks to match the accelerations and velocities measured. The Germans also used the measurements to design flexible mountings ("schwingmetall") for some equipment.

One British problem was that quick-closing fuel valves closed under shock. The Germans had the same problem when their ***Prinz Eugen*** lost power as a result of shock produced by its own depth charges. Both navies went about solving the problem in the same way: a shock test was arranged that would cause the shock-susceptible valve to trip consistently, and the valve was improved until the test no longer produced malfunction. The Germans mounted their valve on the steel-spike impact device for test. The British attached theirs to a loosely-restrained anvil and struck the anvil with a heavy hammer to produce shock. A 400-pound hammer dropped a distance of 5 feet gave the desired results; the test was soon applied to other items of equipment for which shock was a problem. The idea of the hammer-drop shock machine was immediately taken up by the U.S. Navy and (with some improvements by a team under Dr. Irwin Vigness at the Naval Research Laboratory and establishment of the design as a U.S. Standard) is still a mainstay of the shock-qualification program for lightweight equipment. The hammer weight of 400 pounds and the drop height of 5 feet remain unchanged in the present use of the machine.

The U.S. Navy conducted tests against three of its operating submarines in 1941 and 1942 with the objectives of determining any weaknesses under depth-charge attack and of proof-testing shock-hardening modifications. The first submarine tested was seriously damaged as a result of loss of electrical power and shifting of machinery on its foundations. Modifications were made and tested in two follow-on submarines. A fourth submarine was tested in 1946. In this test the overall damage was considered minor, although shock severities 52 percent greater than those for the earlier tests were obtained by locating charges closer to the hull of the submarine. One of the changes recommended on the basis of the 1941 tests was replacement of hold-down bolts for machinery with fitted bolts of high-grade steel. This change was effective: no more machinery shifted. Another change, paralleling circuit breakers with depth-charge switches that would maintain electrical power even if the circuit breaker opened as a result of mechanical shock, was not as uniformly successful. Some of the tests tripped both the circuit breaker and the depth-charge switch, proving that there was no simple substitute for truly shock-proof equipment.

Two captured German submarines (U-1105 and U-3008) were tested at Norfolk Naval Shipyard to determine how close to the hulls depth charges would have to be in order to disable or sink them. The hulls of two uncompleted ships (CL 108 and CV 35) were tested after the war to check the performance of their protection systems and the strength of the hull. In these tests, it was demonstrated that, as Abbot had said in 1881, it was possible to "break her in sunder" by an explosion properly placed beneath the keel. Dr. George Chertock of the David Taylor Model Basin analyzed the data from the cruiser tests and arrived at a simple conclusion: that the best way to break a ship in two from an underwater-explosion attack is to choose exactly the right size of charge so that the oscillations of the bubble of hot gases left after the explosion are tuned to the natural frequency of bending of the hull.

CROSSROADS

"(1) There is no real defense against atomic weapons. (2) There are no satisfactory countermeasures ..." - David Bradley (1948)

"Actually, the problem of defense against an atomic bomb is technically the same as defense against any other type of bomb." - R.E. Lapp (1949)

The biggest test operation ever conducted, or ever likely to be conducted with an underwater explosion, was Operation Crossroads at Bikini Atoll in 1946. Joint Task Force 1 was formed to assemble 42,000 people and more than 80 ships to test the effects of a nuclear device -- the atomic bomb in those days -- that was exploded in the air (Test Able), in shallow water (Test Baker), and in deep water (Test Charlie). The result of Test Baker was decisive enough to put a new word into the English language: a scanty two-piece bathing suit is called a bikini. Test Charlie was cancelled by President Truman, and a truncated deep-water test was not conducted until 1956 as Operation Wigwam.

Instrumentation for measuring the effects of an underwater explosion came of age with Operation Crossroads. The general effects of underwater explosions on ships had been measured by the Germans during their wartime tests on their submarines. The British had a handle on the problem, and the U.S. had made some test measurements from 1941 to 1944. They showed that the explosion of a chemical charge under water near a ship's hull produced three effects: accelerations of the hull capable of breaking loose solidly-bolted equipment (or instrumentation, which was a problem); velocities depending on the size of the charge and its distance; and displacements large enough to assure that anything not capable of withstanding the acceleration would be badly damaged.

Operation Crossroads was a different matter. Test Baker would be a one-shot chance, and no one knew for sure what to expect because a nuclear device had never before been fired under water. Speculation ran from the prospect that it might fizzle like a damp firecracker to the possibility that it might involve the water of Bikini Lagoon and truly eliminate the entire fleet. Mr. Harry L. Rich, who had previously been involved in recording and interpreting shock motions during tests of the submarine U.S.S. ***Dragonet*** (SS 293) in 1944, was assigned the unenviable job of doing the same for Operation Crossroads as part of a Bureau of Ships Task Group.

Rich immediately concluded that the usual method of recording by mirror galvanometers on light-sensitive film would not be satisfactory in Operation Crossroads because of the probability that the film would be fogged by nuclear radiation. He decided to take a chance on the newly-developed wire recorders, which put signals of varying magnetism on a wire wound from one spool to another through a magnetic recording head, but he also doubled up with every kind of transducer and recorder available. Four ships were instrumented to obtain data which could be compared with data from conventional explosives.

Data from the wire recorders were disappointing, but most of the backups worked. Photographic film blackened by radioactive contamination made it possible to distinguish enough traces from the galvanometers to see the effects of the nuclear explosion on the instrumented target ships. Rich wrote part of his report on Operation Crossroads while sitting at a table outside the Banyan Tree Inn, on Waikiki Beach, Hawaii, and there reached his important conclusion that an underwater nuclear explosion is not much different from a chemical one -- it was bigger, and that was all. He was upset to discover on turning in his report that it was classified Top Secret. This was beyond his security clearance, and he was unable to read his own report until it was downgraded some years later. Afterward, Rich liked to refer to a nuclear explosion as a far hit, in comparison with the near miss of a noncontact chemical underwater explosion.

Public accounts of the results of Operation Crossroads led to sharp differences of opinion. Was there a defense? Did the atom bomb mean the end of fleets, navies, and control of the sea? Both the British Royal Navy and the U.S. Navy saw only a problem that had to be solved, and they went to work to find out how to harden ships to resist nuclear-weapons attacks as well as conventional ones. Results of the measurements made during Operation Crossroads were crucial to this study. They showed that shock from underwater nuclear explosions was not a new problem but an extension of an old one.

One feature of Operation Crossroads was that large numbers of people and ships dedicated to investigating explosions against ships were assembled. Many of the personnel continued to make valuable contributions, but only one of the ships did so, as described in the next section.

INSTRUMENTATION

"Bad records are worse than no records at all." - Ed Habib

The crews returning from Operation Crossroads were delighted to find that Commander Bonny, Royal Navy, had published a prescription for putting shock from underwater explosions on a rational and logical basis. In two articles published in a British engineering journal, Bonny used simple formulas and examples taken from shock measured on ships to indicate that after its nature had been properly classified, shock could be controlled and predicted. He said that shock:

- Should be proportional to the square root of the energy per area emitted by the explosive charge;
- Should be proportional to the square root of the cosine of the angle of incidence on the hull of a ship;
- Should be inversely proportional to the square root of the mass per area of the hull; and
- Finally, should have a time-history motion characteristic of the location on the ship, subject to scale factors as described previously.

Bonny's categories were accepted with great enthusiasm in the U.S. as well as Britain. The categories were given the names shock factor, angle factor, mass factor, and shock signature. Test programs were planned to verify each category.

The Naval Research Laboratory moved quickly to take over U.S.S. ***Niagra*** (APA 87) -- a ship that had survived Operation Crossroads -- and to set up a comprehensive series of tests. Tests were designed to measure the shock signature by zones and belts throughout the ship and to provide the proper constants of proportionality for the shock factor, angle factor, and mass factor. Somewhat later, the David Taylor Model Basin took over the uncompleted submarine U.S.S. ***Ulua*** (SS 428) and began a program for determining the same sort of information for submarines. Both programs seemed successful beyond all expectations. After a few tests had been conducted, it was possible to predict within a few percent which measurements would be obtained on the next test.

Of course, some adjustments had to be made. Changing slope was attributed to yielding of the hull. Angles had to be reinterpreted, and the mass factor, the determination of which proved somewhat elusive, was lumped with the shock signature. It was not until 1959 that Mr. George J. O'Hara of the Naval Research Laboratory brought up a relevant question: is not each ship, with its own equipment, a unique case? Isn't it improper to use predicted shock motions from one ship to determine the effects of shock on different equipment in a different ship, especially if the predictions are to be used to make changes in the equipment or the ship to improve its resistance to shock?

TEAMWORK

"Have you heard of the wonderful one-hoss shay,
That was built in such a logical way
It ran a hundred years to a day?" -
Oliver Wendell Holmes

The shock-test teams measured shock effects on more than 70 ships over the 30 years from 1948 to 1978. Ship types ranged alphabetically from APA to YMS, and by size from minesweeping launches to aircraft carriers.

Early tests were conducted using depth charges, which had to be carefully placed close to the hulls of the test ships to provide the desired intensity of shock. The risk was that a test would be described as "Oops, too close!" Sizes were increased until charges containing 5 or 20 tons of high explosive became standard. A single test from a great distance with such a charge could shock a large ship from stem to stern and provide shock data on equipment located throughout the ship.

Most shock tests are conducted using operating ships with a full crew ready to take action to control damage as necessary. One question that always comes up is "Where is the shock-test crew going to be when the charge blows up?" The answer is always the same: "Right here on board ship with you, running our recorders."

Some tests have been conducted at such high levels that there was some danger of losing the ship. In these cases all personnel are removed, and recorders are remotely operated. Boarding parties stand by out of range of the explosion until the test has been conducted. The object of tests conducted with a crew on board has been to locate particularly weak items which could be upgraded to make the shock resistance of the ship as uniform as possible; that is, to make the ship a "one-hoss shay" in which every part is equally strong. The more severe tests were conducted to research conditions that would have to be met close to the survival limit.

Shock-test teams have usually had a difficult time when they approach a particular ship and announce their intention of shooting at it with 20-ton charges to see what breaks. It has also been difficult to approach a shipyard for assistance from machinists, welders, shipfitters, electricians, and riggers for installing instrumentation and surveying damage when such work obviously interferes with schedules for more useful work and is seemingly aimed at destruction rather than construction. With practice, the members of shock-test teams developed roles to make their approach more effective.

The two essential people on a shock-test team are the Agitator and the Good Guy. The Agitator threatens, shouts, and demands that things be done. The job of the Good Guy is to be kind and understanding and to soothe the feelings ruffled by the Agitator. Without an Agitator, a pleasant time would be had by all, but the work would never get done. Without the Good Guy, the crew of the ship and the shipyard would close ranks against the unreasonable demands of the shock-test team, and the work would never get done. One of the great pleasures of being on a shock-test team is to see how quickly a key person at a shipyard can be changed from a position of disinterested hostility to one of enthusiastic cooperation by a sequence of properly-spaced visits from an Agitator and a Good Guy.

Other useful but not essential roles include the Glorious Leader, the Work Horse, and the Resident Genius. The Glorious Leader's job is to show cheerful imperturbability in the face of difficulties and unconcern over disasters. His calmness is not of course due to a lack of understanding but to the fact that he considered all difficulties and disasters in advance. Nothing, therefore, catches him by surprise. Whether he gives advice or not is less important than his attitude as he considers an immediate problem. You see him ticking down his list to Disaster Number 14 Subclass C, "There are at least three alternatives, don't you think? I am sure one of them should solve the problem."

The Work Horse begins early, works late, and never *seems to quit. Only one is needed per team.* He inspires all who observe him to begin a little earlier, quit a little later, and hang in there. It's hard to complain that you are being overworked when you're confronted with the record of a Work Horse. His outstanding feature is that he remains cheerful at all times.

The Resident Genius is the only role that is not freely interchangeable among the members of a shock-test team. This person has special expertise that other members of the team draw upon as necessary. It would seem that there ought to be several Resident Geniuses in a shock-test team, each specializing in a particular area, but for some reason this has not been the case. Most Resident Geniuses, after establishing their role, seem to be accepted as experts for everything -- from how to correct the speed control in a malfunctioning tape recorder to selecting the best restaurant near the shipyard for steaks.

Although most roles of a shock-test team are interchangeable, and most of the people in the teams have filled one role or another during different tests, it is not usually wise to change roles during a particular test. It causes confusion when a Glorious Leader suddenly becomes an Agitator.

One of the best Agitators was Harry Rich, from the Model Basin team, although he was also an extremely effective Glorious Leader and a Good Guy on other occasions. Ray Converse Jr., from the Model Basin, may have been the greatest Good Guy of all time. Ed Habib and Bob Ruggles from the Model Basin were Glorious Leaders (on different tests). Memorable Work Horses were Merv Oleson from the Naval Research Laboratory (he was also a Good Guy and a Resident Genius), Johnny Bachman from the Laboratory, and Bill Carr and Paul Shorrow from the Model Basin. Charlie Lemich from the Model Basin was an example of a combination of Work Horse and Resident Genius.

It ought to be possible to select an all-star shock test team that could most effectively get cooperation from a shipyard and a crew, run a difficult set of tests in the face of severe constraints on schedules and funds, and produce the best analysis of the results but, as suggested above, the result would be too biased. The effective team from the Underwater Explosions Research Division is not represented herein because the author lacks personal experience, nor are the smaller teams from the U.S. Navy and foreign navies included. Test reports have shown that the West Coast Shock Facility in San Francisco had done great work on significant tests. The Shock and Vibration Bulletin has published reports from a shock-test team in Sweden using highly-advanced instrumentation and a submersible shock-test vehicle named "Stalmyggan," which means "Mighty Mosquito" in Swedish. And the British team, operating out of Dunfermline, Scotland, with the great Peter B. Wishart, has not been mentioned at all. There is nothing to do but drop the whole matter and label the preceding discussion as an irrational, emotional, and personal set of impressions.

CONCLUSION

***"A chield's amang you takin' notes,
And faith he'll prent it." - Robert Burns***

This history of shock testing of ships with underwater explosions is too limited and personal to be considered a comprehensive history of the efforts of the U.S. Navy to strengthen its combat fleet.

The list of people mentioned is also incomplete and personal. It omits, for example, the guidance given to the shock-test programs by Russ Oliver and by Jerry Sullivan of the Bureau of Ships.

It is hoped however that these pages have given the reader some indication of what it is like to be on a shock-test team and how results from tests can be cycled back to the fleet. The objective of tests has been to improve present warships and provide future ones that can withstand attacks from a determined enemy and continue to perform their mission.

LITERATURE REVIEW

survey and analysis of the Shock and Vibration literature

The monthly Literature Review, a subjective critique and summary of the literature, consists of two to four review articles each month, 3,000 to 4,000 words in length. The purpose of this section is to present a "digest" of literature over a period of three years. Planned by the Technical Editor, this section provides the DIGEST reader with up-to-date insights into current technology in more than 150 topic areas. Review articles include technical information from articles, reports, and unpublished proceedings. Each article also contains a minor tutorial of the technical area under discussion, a survey and evaluation of the new literature, and recommendations. Review articles are written by experts in the shock and vibration field.

This issue of the DIGEST contains review articles on the techniques and applications of mechanical signature analysis; and damping in structural joints.

Mr. R.H. Volin of the Shock and Vibration Information Center has written a review of techniques and applications of mechanical signature analysis. Its use in monitoring the condition of rotating machinery is emphasized because the vibration is self generated.

Dr. C.F. Beards of the Imperial College of Science and Technology, London, has written a review of damping in structural joints. The frictional damping mechanisms that can occur in structural joints are discussed.

TECHNIQUES AND APPLICATIONS OF MECHANICAL SIGNATURE ANALYSIS

R.H. Volin*

***Abstract** - Mechanical signature analysis is a process of monitoring the vibration signatures of operating machinery systems or their components to determine their condition. It can also be used to diagnose the cause of a fault. The extensive literature on this subject includes the sources of vibration in rotating machinery, instrumentation, measurement techniques, data processing techniques, applications to various types of machinery and systems, and the experiences of users. This paper is a review of mechanical signature analysis. Its use in monitoring the condition of rotating machinery is emphasized because the vibration signature is self generated. But the technique is equally useful for determining the condition of systems whose vibration signatures are externally excited.*

Many systems generate secondary effects or characteristic signatures as a result of their operation [1]. These effects are not normally used in the operation of the system, and their levels are often a direct indication of the condition of the system [2]. Mechanical signature analysis is a process of monitoring the characteristic signatures of a system to determine its condition; it can also be used to diagnose the cause of a malfunction. Vibration signatures in rotating machinery, or its components, are indicative of condition and are produced during operation.

In this review emphasis is placed on the use of signature analysis to determine the condition of rotating machinery; however, the technique can also be used to determine the condition of systems in which the signature is generated by external excitation. In some cases a signature is generated mechanically, but the condition of the system is determined by measuring its acoustic output.

CHARACTERISTICS OF MACHINERY VIBRATION

The first step in implementing a successful machinery condition monitoring program is selecting the components to be monitored. The decision should be based on the vulnerability of either the production phase or operational phase to failure of a particular machine [3, 4]. Other considerations -- type of service, availability of spares or operating experience -- also influence the selection of machinery to be monitored and the monitoring system.

Knowledge of the sources of machinery vibration is important in designing a machinery condition monitoring system. For example, rotating machinery has lateral critical speeds, and, according to Traexler [5], the design of a machine can be so complex that it has a broad spectrum of critical speeds between zero and its operating speed. With such systems, tuning a machine so that its operating speed does not coincide with a critical speed can be very difficult. As a result the trend has been to accept or reject the design of a rotor on the basis of its allowable vibration response at the journals at various speeds. Thus machinery in good condition can be expected to produce some vibration.

Rotating machinery also has torsional natural frequencies, and, according to Eshleman [6], stress in components rather than the motion of components is of concern. Traexler [5] has also pointed out that the torsional natural frequencies of rotating systems are tuned to avoid coincidence with all known sources of excitation. Torsional vibration is often complex. Start up of synchronous electric motors, abrupt start-ups, and gear inaccuracies are typical sources. A method has been developed for analyzing the torsional response of a compressor shaft to the

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oscillating torque produced by synchronous motor start up [7].

Rotor whirl, or oil whip, is another form of undesired motion in rotating machinery. It appears as a suddenly-developed instability at some speed between the first critical speed and the operating speed, or somewhere from 40% to 60% of operating speed. Compressors and multistage turbines whose operating speed ranges from 5,000 - 15,000 RPM are often susceptible to this behavior [8]. Machinery with journal bearings also seems to be prone to rotor whirl [3].

Blade resonance is another source of vibration in turbomachinery. In some cases the blades can be tuned to avoid certain frequencies. In other cases they can be designed to survive the resonance.

Other sources of vibration in rotating machinery include misalignment between major elements in a rotating machinery train, misalignment between internal components, local structural resonances, and vibrations of individual components, including fans, bearings, and gears. Equations for predicting the frequencies of bearings and fans [9] and gears [10] are available.

Small changes in process conditions, alignment, or foundation stiffness often significantly affect vibration levels of machinery. For example, if bearing assembly bolts loosen, the effective stiffness of the bearing foundation might change and affect the critical speed of the shaft.

Factors to be measured and measurement locations depend on the construction of the machine. Rotating machinery with hydrodynamic journal bearings has been divided into two groups [4]: high casing to rotor weight ratio (stiff bearing supports) and low casing to rotor weight ratio (flexible bearing supports). Centrifugal compressors are cited as examples of the former; centrifugal pumps are an example of the latter [11]. Rotating machinery has also been separated into three groups. Two are the same as those mentioned above. The third includes machinery equipped with rolling element bearings [12]. Rotating machinery has also been classified according to whether the bearings are supported on pedestals or in the casing [13].

Three basic types of machinery vibration measurements involve measuring the bearing cap or casing vibration, measuring the shaft vibration relative to the bearing, or measuring the absolute shaft vibration (a combination of shaft vibration and bearing cap vibration). Measurements of factors other than vibration -- temperature, pressure flow rate, and shaft axial position -- are sometimes necessary to completely define the condition of the machine or provide protection. Vibration is generally measured at locations most likely to reveal significant increases in the event of mechanical problems. In some cases, however, this is not practical. Measurement of bearing cap or casing vibration is recommended for heavy rotors supported on flexible bearing supports. Such measurements are more sensitive to a change in the condition of this type of machine and should also be used on equipment supported by rolling element bearings. Relative vibration measurements of shafts should be made on light rotors supported on rigid bearing supports [4, 12].

STANDARDS AND CRITERIA

Mechanical signature analysis is a comparative process. Vibration signatures can be compared to baseline signatures, to previous signatures obtained from the system, or to vibration signatures from identical systems or machinery known to be in good condition. Signatures can also be compared to established standards. One objective of this process is to predict when the condition of a system has deteriorated to the point that some type of failure is imminent. However, the significance of an abnormal measurement poses problems that possibly limit the monitoring process.

Sankar and Xistris [14] have observed that random fluctuations in vibration signatures are not considered in some monitoring techniques. Some machinery vibration signals vary randomly, and it is possible for a signal to momentarily exceed a safe level even though the mean value of the signal is below the safe level. A method for determining the onset of failure involves using random variations of data in a vibration record to predict both the first passage probability of a vibration signal above a safe level and the propability that the vibration measurement will exceed the safe level for a given duration [14]. Piety and Magette [15] developed a technique for

testing vibration signatures to determine if their deviations from baseline values are statistically significant and indicative of deterioration. This technique is implemented on a minicomputer-based monitoring system and has been evaluated in laboratory tests of a small rotor assembly. Another machinery condition monitoring procedure [16] is based on the accumulation of fatigue damage in specific machine elements. The stress histories are assumed to be some linear function of the measured vibration histories, and expressions are derived for predicting the estimated fatigue damage as a function of the measured vibration histories. This procedure can be used to determine the remaining life in a machine rather than the onset of failure. Collacott [17] has also proposed a technique for determining the condition of a machine and predicting its remaining life. He divided the operating or whole life of a machine into two regions: infant mortality, in which failures might result from initial defects, and life mortality, in which failures occur due to eventual wearout. Simple equations can be used to predict the time of minimum probability of failure at the end of the infant mortality region and the time of certain failure in the life mortality region. The whole life of a machine can thus be predicted.

Figure 1 shows variation of a vibration signature with time in three regions of total operating life. It also shows the change of vibration levels with time in three regions of the life of a system. Most important is the variation in rate of change of vibration level at point B, the beginning of the region of increased wear. The objective in monitoring machinery vibration is to determine when the rate of

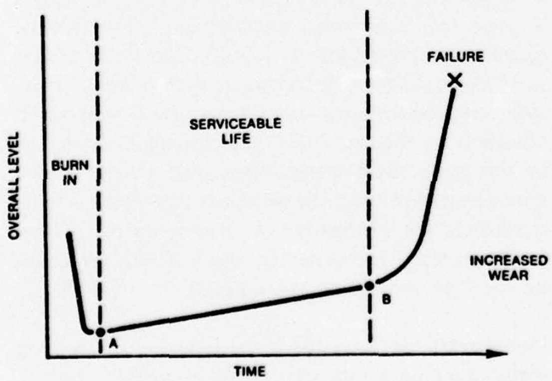

Figure 1. Vibration Level vs Time for Three Operating Regions of a Mechanical System

change in vibration level begins to change or when the rate of change in vibration level has increased. This figure is applicable to the machinery baseline signatures described below.

Baseline signatures imply fault-free operation. It is thus essential that the machine be in good condition; it should operate under standard conditions and should be in its final installed state (point A in Figure 1). A meaningful baseline signature cannot be obtained unless these conditions are met [18, 19]. A baseline signature on a newly installed blower, for example, revealed vibration caused by looseness, unbalance, and aerodynamic forces. Because the outlet piping to the blower had not been completed, the vibration amplitude due to aerodynamic forces was high. After the piping was completed, the vibration amplitude due to aerodynamic forces was reduced. Other mechanical problems have been uncovered by baseline analysis during start-up of new or overhauled equipment [18]. The baseline technique for determining the condition of machinery has been discussed [11, 20, 21].

No discussion of criteria and standards would be complete without consideration of acceptable vibration levels. Among several curves that exist, one of the earliest was the "Rathbone Chart," a family of curves showing allowable vibration levels as a function of frequency for machinery operating conditions ranging from extremely smooth to extremely rough. This chart has been reproduced [19]. Another chart is the IRD Mechanalysis General Machinery Vibration Severity Chart. Machinery vibration tolerance charts attributable to Blake, Yates, and MIL-STD-167* are available [22]. They represent allowable vibration limits measured at the bearing cap or bearing pedestal of rotating machinery. One compressor manufacturer has published a vibration severity chart for medium- and high-speed centrifugal compressors that is based on relative vibration of the shaft. This chart is restricted to equipment manufactured by the company [23]. Rough guidelines have been proposed for GO-NO GO limits for turbomachinery [13, 24]. Specialized standards for the severity of vibration for electric motors and high-speed gear reducers have been proposed. Their usefulness may be limited, however, because vibration is evaluated when the machines are isolated. ISO 2372 divides machinery into six classes and suggests a method for rating the vibration severity of each class [25]. Eshelman [26]

**Military Standard 167, "Mechanical Vibrations of Shipboard Equipment"*

has presented a complete discussion of standards for allowable vibration. It is important to note that no absolute values of the severity of machinery vibration signatures exist – that the same value could mean satisfactory operation on one type of machine and imminent failure on another [13, 19, 22-24, 26, 27].

MEASUREMENTS AND INSTRUMENTS

Three variables can be used to measure vibration: displacement, velocity, and acceleration. Velocity has several advantages. One is that wear is a function of the amplitude of motion and frequency and that velocity is a combination of the two factors. Therefore, a single measurement describes the condition of a system over a broad frequency range. Velocity identifies significant vibration frequencies over a broad frequency band; displacement and acceleration tend to emphasize the minimum and maximum of the frequency range respectively. Thus velocity measurements might provide greater sensitivity to change in the condition of machinery or systems that can develop a variety of mechanical problems [12, 27, 28]. Velocity measurements can be expressed in dimensional units (cm/sec, in/sec or in dimensionless form, the velocity decibel, or Vdb, which is defined as [29]

$$\mathrm{Vdb} = 20 \log \left(\frac{V}{V_{ref}}\right) \qquad (1)$$

V = measured velocity in cm/sec

V_{ref} = reference velocity equal to 10^{-6} cm/sec

Both forms appear in the literature.

The other variables are also used. For example, relative motions of a shaft can be monitored by proximity probes in terms of displacement. The high frequency vibration generated by such components as bearings and gears might be measured in terms of acceleration.

The most common transducers for measuring vibration are proximity probes, velocity pickups, and piezoelectric accelerometers. Mitchell [30] has reviewed the characteristics, applications, advantages, and limitations of the three types. The piezoelectric accelerometer seems to be the most popular contact transducer for measuring bearing housing vibration because of its wide dynamic range. One of the more popular methods for mounting contact transducers is to use magnets. The user should be aware, however, that an improperly mounted transducer leads to measurement errors that result in invalid data. The writer believes that this point should be stressed. The use of magnets or isolated mounting studs reduces the natural frequency of piezoelectric accelerometers and consequently their useful frequency range. This does not mean that the mounting methods are improper. Further discussions of the characteristics of piezoelectric accelerometers and the types of measurement errors that can occur when using this type of transducer are available [26, 30, 31].

The proximity probe is used to make relative position measurements of shafts and is also subject to mounting or measurement errors that result in invalid data. Placement of a probe at or near a node in a shaft is an example of the former. Runout, which can be caused by eccentricity between a shaft and its journal or by scratches in the shaft, is an example of the latter. Frarey [32] presents an extensive discussion of the causes of runout error, its effects on vibration measurements, and methods for compensating for it. Other discussions of this source of error are available [4, 30, 31].

Transducers used in machinery monitoring are often required to withstand corrosive environments and temperatures from 130°C to 260°C (250° to 500°F). In addition, cables may be routed through areas where temperatures reach 900°C [33, 34].

Several new or unusual types of sensors have been used to measure vibration in mechanical signature analysis or diagnostic applications. A telemetry system was developed to acquire data from blades in a steam turbine. Strain gages were used to measure frequencies and amplitude of flow-induced vibration on blades. The strain gage signals were fed to miniature radio transmitters that operate in the commercial FM band. Because the strain gage output modulates the FM carrier wave in a manner similar to commercial broadcasting, the FM receiver could be used to receive or demodulate the signal [35].

Piezoelectric pressure gages mounted on the cooling water inlet or outlet of a nuclear reactor pressure vessel were used to detect both the pendular and vertical vibration of the reactor structure and its

internal components. Ionization chambers used to monitor neutron flux were also used to monitor relative pendular motion between the reactor core and the pressure vessel. Accelerometers were not as suitable for monitoring the structural vibrations of the reactor pressure vessel because most of the vibrations were less than 60 Hz. However, they could effectively detect loose particles [36]. A technique for detecting vibration in Diesel engine liners utilizes techniques for monitoring the corrosion of liner materials [37]. Vibration of the liners increased the mass transfer rate in an electrochemical reaction; this increase is related to the value of the limiting current sustained at the electrode of a monitoring probe.

An optical technique has been used to detect a faulty rolling element bearing [38]. A fiber optic probe measures the deformation of the bearing races and the ball passage frequency. The rotational speed of the shaft is measured independently. A nominal design value of the ratio of the rotational speed to the ball passage frequency was established for a bearing in good condition. If the bearing is in good condition, the electrical output of the probe should result in a clean sine wave on an oscilloscope. A defective bearing will result either in a distorted sine wave or the shaft rotational speed to ball passage frequency ratio will deviate from the nominal design value.

A piezoelectric polymer gage developed at the National Bureau of Standards was constructed from a polymer material that was made piezoelectrically active. Its ability to detect vibrations characteristic of a faulty rolling element bearing was evaluated and compared to a piezoelectric accelerometer. The piezoelectric polymer gage has many advantages: high resonance frequency, (in the MHz range), the ability to be mounted to and conform to any shape, and the ability to be mounted next to a vibration source. The evaluation showed that the gage has potential, but the effects of temperature response remain to be evaluated [39].

An optical technique has been developed for continuously monitoring the flutter of gas turbine compressor blades. A laser is used as a coherent light source; the light illuminates two retroreflectors attached to the blades. The reflectors return the light to the source and mix it to form a pattern of fringes at the source. Relative motion between the retroreflectors produces a shift in the fringe pattern that is proportional to the deflection of the object carrying the retroreflectors [40].

A technique has been developed to measure the instantaneous torsional oscillation during start-up of a synchronous electric motor. Two piezoelectric accelerometers mounted back to back on a disk monitor the pulsating start-up torque, which is proportional to the angular acceleration. The accelerometer output is fed through the slip rings for signal conditioning and recording. The shaft strain on the driven system can be monitored by strain gages or telemetered to a receiver and signal conditioner [41].

After data have been taken, some provision must be made to either store it for further processing or read it out. The former is done by tape recorder; a frequency modulation tape recorder (0 - 15 KHz frequency range) can be used [42]. Readout can be provided by portable meters or portable analyzers.

DATA ANALYSIS

A vibration signature measured on a system or on machinery is in the time domain and indicates overall RMS level. It is complex for several reasons. First, the transducer used to make the measurement often has a wide frequency response. In addition, the measurement is often made at a point remote from the source of the signature so the transmission path modifies the characteristics of the measurement. Finally, the measurement could represent several sources, each with multiple transmission paths. In some cases -- simple systems or machines or measurements with little or no harmonic content -- a change in the overall RMS level is sufficient to indicate a change in condition of a system or a machine. But this is not always true because changes in individual spectral content can indicate changes in condition even though these changes alone do not affect the overall RMS level. Therefore, some form of data analysis is necessary either to detect the change in condition or to determine the cause of a change in condition.

A spectral analysis or a frequency analysis is usually performed on vibration data. The frequency domain is preferred because of the relative ease of correlating

measurements and specific events in the operation of a system [43-46]. However, in the case of reciprocating machinery, time domain analysis may be more advantageous because faults are more likely to show up as changes in time history than in spectral content [43]. Questions often arise over the best format for data presentation and frequency resolution. The full octave band affords the lowest degree of frequency resolution. One paper, however, has described the use of an octave band analyzer to analyze data and diagnose the cause of a fault [21]. Finer frequency resolution can be obtained with a smaller constant percentage bandwidth analysis or a narrow band analysis. Most investigators favor a discrete frequency band analysis over a constant percentage bandwidth analysis [21, 27]; however, a conflict often arises between the need to cover a wide frequency band rapidly and the need for fine frequency resolution [43].

Errors in computing frequency domain functions can lead to errors in data interpretation. A useful paper that is not specifically on the subject of mechanical signature analysis [47] emphasizes some of the sources of computational errors and ways to minimize them. For example, leakage occurs in any Finite Fourier Transform of a non-periodic signal that distorts the shape of the spectrum. The proper duration and window shape -- cosine taper, Hann, or exponential -- can reduce the unwanted effects [47].

A research program evaluated the effectiveness of various signal processing techniques for determining the condition of mechanical components of helicopter power trains [44-46]. Pattern recognition and mechanically-based diagnostic techniques in determining the condition of a system were also compared. Pattern recognition techniques are based on statistical treatment of data. Mechanically-based diagnostic techniques rely on the dynamic characteristics of the system being tested. Various time domain and frequency domain techniques for indicating changes in condition of both bearings and gears were investigated. Both in-flight helicopter vibration data and data generated on a bearing test rig were used. Mechanical diagnostic techniques showed more promise as helicopter power-train condition indicators because they are more flexible. The frequency domain is more popular for processing the data because specific operating events can be correlated with specific frequencies [44-46].

Most machinery noise is due to operation -- a mixture of periodic components and Gaussian background noise. Spectral techniques can be used to analyze machinery noise that includes these components. Bispectral analysis is a new technique that is sensitive enough to detect the slight changes in system condition that show up as changes in the phasing between the frequency components of a signature [48].

As pointed out earlier the vibration spectra of measurements from systems or machines are complex because of the influence of the transmission path(s). Cepstrum analysis is a data processing method that can be used to separate the periodic effects in a vibration spectrum. The mathematical definition of the cepstrum is the power spectrum of the logarithm of the power spectrum. Note that the cepstrum performs the same function as the autocorrelation function; however, effects multiplied in the power spectral analysis are additive in the cepstrum analysis [49].

The use of time domain averaging for detecting periodic signals is well known. Data processing in the time domain can be used to identify the source of vibration in and the condition of certain types of rotating machinery. However, vibration signal from rotating machines are not totally periodic; hence, it is difficult to determine the characteristics of rotating machines locked to rotation. One digital data processing method uses time domain averaging to decompose a time signal into terms that are time locked to the fundamental rotation period and into residual signals; the method is used to extract the rotation locked signals generated by rotating machinery. Digital filtering in the frequency domain was also proposed for extracting periodic signals from rotating machinery; however, it applies only to leakage-free signals. With signals that are not coherent with the rotational frequency of the machine, errors could distort the desired signal components. The use of the appropriate windows minimizes this effect [50].

Another approach for extracting weak periodic signals from almost periodic signals generated by rotating machinery is to compute changing variances. This scheme is based on a combined computation of averages and variances. It is done in real time; hence, the running variance is computed instead of the true

variance. If sufficient samples are taken the running variance approaches the true variance. This technique has been extended to non-stationary vibration signatures [51].

A statistical analysis technique has been developed for determining the condition of rolling element bearings [52]. The fourth statistical moment, or kurtosis value, of the bearing housing acceleration signal was selected as the best indicator of a change in bearing condition. The probability density distribution of the measured bearing acceleration must be determined before the value of the kurtosis of the amplitude distribution is determined. A Gaussian distribution results in a finite kurtosis value; this distribution indicates a sound bearing. Measurement of the kurtosis in selected frequency bands and at different times makes it possible to determine the severity of damage [52].

Many systems generate continuous high frequency vibration, modulated resonances, or periodic or non-periodic modulated resonances. The modulation often indicates the presence of a fault. Band passing and envelope detection of a vibration signature make it possible to extract diagnostic information. This technique is also known as the high frequency resonance or the detected carrier technique. The advantages of this technique are that the electronics are not driven to saturation by the high frequencies and the electrical noise found in many signals is not present. Perhaps more important is that the equipment needed and the data processing are relatively simple and inexpensive [53, 54].

Three unique data processing techniques have been developed. The first, a digital computer-based technique, is programmed to vary the intensity of a printout on a line printer as a function of the power spectral density at each frequency. The technique was used to diagnose the implanted defects in a cam and follower mechanism [55]. A feasibility study has been done to determine the ability of optical spectral analysis to detect faults [56]. Optical spectral analysis allows sharp frequency resolution; the ability of the technique to separate peaks was tested during spectral analysis of transmission vibration data. A third technique uses a composite exceedance method based on a count of the positive and negative peaks in an acceleration-time history in specific amplitude bands [57].

Data analysis instrumentation ranges from tunable band pass filters through spectrum analyzers to digital computers. Jackson [58] describes the characteristics of some of the more common types of instruments. The Sea Element of the Canadian Armed Forces developed a shipboard vibration data acquisition and analysis system; the heart of the system is a real time octave band analyzer [59].

A data analysis system was developed to meet the need for rapid processing and displaying of gas turbine stress and vibration data as functions of both frequency and time [60]. The users were unable to find a commercial system to meet their needs and so they built a system that displays amplitude vs frequency and time on a single plot with two traces. In one case the intensity of the trace is proportional to amplitude; in the other it is proportional to frequency.

A prototype of a bispectral passive imaging system was built to perform a bispectral analysis of acoustic signatures from rotating machinery [61]. A minicomputer processes the acoustic signals to derive an acoustic hologram that reconstructs the image of signals coherent with the rotation of the machinery [61]. The technique has been discussed [48].

A digital computer was installed on board a cargo ship to perform not only the data processing function but also the command and control functions for monitoring the condition of shipboard propulsion machinery [20]. In most cases minicomputers are used. The application of minicomputers to machinery condition monitoring can be justified for many reasons: lower initial cost than newer less powerful machines; lower cost than hardwired individual vibration monitors and alarms if many systems are involved; and flexibility and varied capabilities. A major limitation of minicomputers is reliability; thus, critical machinery or systems must be provided with backup monitoring and alarm systems [62].

BEARINGS

Rolling element bearings exhibit characteristic wear rate/failure patterns similar to the vibration level vs time curve in Figure 1. The ordinate is wear rate, which is proportional to vibration level. However, the failure point for a bearing is at or near point B which indicates the onset of increased wear.

Monitoring the condition of rolling element bearings requires determination of the point at which the rate of change in vibration level begins to change. This occurs at point B in Figure 1. Rolling element bearings accumulate fatigue cycles during their serviceable life; hence, many failures are fatigue initiated [1, 44]. In addition, slight imperfections generate vibration when the elements contact one another during rotation; so long as the imperfections are slight, the bearing assembly should be serviceable. The characteristic frequencies of rolling element bearings are a function of geometry and rotational speed. Equations for predicting these frequencies are available [10, 44, 63]. Each bearing component has a resonance frequency dependent on geometry, loading, and bearing material. These frequencies, which are higher than rotational frequencies, are excited when a component passes a flaw in another component; e.g., a roller passing a scratch in the outer race.

Various techniques are used to diagnose the condition of rolling element bearings. Spectral analysis has been used in connection with spectral averaging to detect implanted faults in aircraft engine bearings on a commercial bearing tester. This technique was capable of detecting a faulty bearing provided background noise was controlled. Some of the defects would not have been found by normal inspection procedures [63]. The sensitivity of various parameters -- overall vibration level, spectral analysis, detected carrier spectrum analysis, carrier rms level, and amplitude distribution of the carrier signal – for determining the condition of rolling element bearings has been studied [64, 65]. Data were obtained on good and defective (implanted defects) rolling element bearings. The high frequency techniques, particularly detected carrier spectrum analysis, was the most sensitive to a deterioration in the condition of rolling element bearings. Other evaluations of the sensitivity of this technique to rolling element bearing damage are available [53, 54, 66]. In one case [66] the technique was evaluated using bearings in a bearing rig and also in the main transmission of a helicopter. It was shown [54] that this technique could also detect journal bearing film rupture and thrust bearing rub.

Kurtosis of the vibration signature of a tapered roller bearing has been evaluated as an indicator of bearing wear [52]. It was possible to detect deterioration in bearing condition at an earlier stage than with measured peak or rms acceleration values. The main advantage of kurtosis is that it predicts the earliest onset of failure; i.e., point B in Figure 1. The feasibility of using signal decomposition techniques [50] to determine bearing wear was evaluated with data obtained from a bearing rig. This data processing method made it possible to identify defects in the outer race of a rolling element bearing that could not be detected by spectral analysis [67].

An optical technique for detecting damaged bearings has been evaluated by monitoring an electric motor bearing. Damage was observed after three hours of operation. When the same bearing was monitored with an accelerometer mounted on the motor frame, the accelerometer measurements gave no indication of the onset of damage [38]. Measuring shock pulse emission rate is another technique for detecting bearing damage [68]. Detection of faulty bearings in the laboratory and in a helicopter transmission has been discussed [69]. Crest factor analysis, which indicates the size of a fatigue spall in rolling element bearings, is based on the peak to rms ratio of the processed signal; the signal increases with spall size [70].

GEARS

Gears generate mechanical signatures that are periodic with meshing frequency – the number of teeth and shaft speed. The meshing of two teeth produces impacts even if the gears are operating properly. Gears can also have such local defects as worn or chipped teeth, and the defects can be distributed due to pitch diameter errors or shaft eccentricity. The last two faults cause sidebands to develop at several orders of rotational speed of the shaft [44].

Detection of gear faults is relatively easy, but interpreting the mechanical signatures in terms of gear condition is often difficult. The reason is that many faults show up at the gear mesh frequency. Detected carrier spectrum analysis has been proposed because one type of gear defect might excite certain types of resonances in the gear housing or machine structure, but other defects might excite entirely different resonances [66]. Bispectral analysis of gear noise is used to detect slight changes in gear condition in which the amplitude of each frequency component is unchanged. The feasibility of this technique was demonstrated during tests to detect the scoring in gear teeth produced by an increased load [48].

Another technique for determining the degree of wear in gears is summation analysis, which enhances the periodic characteristics of a mechanical signature and cancels the noise. Summation analysis has been used to determine the signature of a transmission with sound gears and to detect the signature of one gear in which a tooth was intentionally damaged [71].

Mechanical signature analysis has been used to detect many types of gear defects, including defective teeth and problems associated with meshing of teeth.

Other techniques used to identify gear defects include observation of the time history signal, spectral analysis, and sum and difference frequencies. Proper location of the transducer is essential in order to identify the source of a gear defect. Vibration analysis techniques used to identify gear defects in operating machinery have been described [72]. Composite exceedance was used to detect a spalled tooth surface in a turbine shaft pinion gear. A PSD-based signature analysis found the same anomaly but the data processing time was twice that for composite exceedance [57].

PUMPS AND VALVES

Several mechanical signature analysis techniques are available for assessing the condition or degree of wear of pumps and valves. Maroney and Tessman [73] developed a noise wear index for pumps and used it to determine the degree of contaminant wear in gear pumps. An acoustical measure of a mechanical signature is used to measure noise due to operation of the pump. The technique involves matching the overall noise level, as well as noise levels at a few lower pumping harmonics, to the ratio of amount of flow to rated flow, or the flow performance index. The detected carrier spectral analysis technique is capable of detecting or diagnosing faults that would not be picked up by conventional low frequency spectral analysis. Typical defects might be due to high frequency sources of excitation such as rolling contact, impact, or sliding [74].

Early detection of valve leakage in reciprocating compressors is necessary to avoid the possibility of further damage. The detected carrier spectral analysis technique has been used. Two measurements are made. One is the rms vibration level, which is used to diagnose the presence of a leaky valve or a poorly seated valve. The other measurement, the ratio of spike energy to threshold rms energy, indicates the severity of impact. The latter measurement can also be used to indicate the condition of the valve spring [75].

ROTATING MACHINERY

Mechanical signature analysis has been used to monitor the condition of many types of rotating machinery -- pumps, fans, compressors, turbines, and electric motors. The technique has also been used to detect shaft rubs, seal rubs, blade vibration, and starting transients in electric motors.

In an early study Bannister and Donato [76] examined the feasibility of extracting the mechanical signatures of steam turbines to determine their condition and to detect mechanical problems. They examined transducers needed to make the measurements and the data processing techniques necessary to translate measured signatures into meaningful information about machinery condition. Methods were also described for detecting blade vibration from the complex signatures measured at the bearing housing. Many of the measurement and analysis techniques proposed by Bannister and Donato are now standard practice.

Techniques for monitoring bladed machinery have also been discussed [77]. General techniques were given for detecting blade frequencies and specific techniques for problems experienced in extracting vibration signatures from axial compressors, steam turbines, and gas turbines. Bladed machinery tends to generate high frequency vibration signatures with many spectral lines. This affects both the monitoring techniques and the measuring systems used [77].

Two case histories of monitoring gas turbines have been published [13, 29]. One case involved an industrial gas turbine whose vibration characteristics showed both significant amounts of bearing housing motion and a node in the shaft motion relative to the same bearing housing. Measurements of both absolute and relative vibration signatures are necessary on this type of machinery [13]. The other case involved monitoring a 750 kW shipboard gas turbine

generator. This type of machine has rigid casings and frames; hence, these points do not have high vibration levels. In addition, only a limited number of points are accessible for measuring vibration. The rationale behind the selection of the monitoring stations and the measurements that could be obtained at each station was described. The results showed that a few well chosen points can be used to extract meaningful vibration signatures of components and accessories even though some measurements were not made near the source of vibration [29].

Experience gained in monitoring the signature of 16 axial flow compressors in a test loop will be extended to all compressors in a uranium enrichment plant. Measurements were made with piezoelectric accelerometers on bearing caps; the measured vibration can be used to determine the condition of the blades as well as whether a stage has lost any blades [34].

Abnormalities often occur in the magnitude and frequency of the AC component of the air gap torque of an electric motor at start-up. Such abnormalities can excite damaging torsional resonances in the shaft of the driven equipment without leaving any evidence of the cause. A monitoring system has been developed that aborts a start-up if starting torques are abnormal [78]. The shaft torque of the motor was not monitored because torsional vibrations might not be detected until it is too late. Instead, the motor inrush wattage is measured; the strength and duration of the AC component indicates whether a start is normal or abnormal.

GROUND VEHICLES

Sources of vehicle power train vibrations include unbalanced parts, misalignment, eccentricity, faulty bearings, and defective drive belts. A list of the sources in terms of multiples of the rotational speed is available [28]. Mechanical signature analysis techniques could be used to determine the condition of the power train of a truck and to diagnose the source of faults [28]. A simplified technique called the rotational synchronous approach was developed for diagnosing faults in truck power trains. It is based on correlating a pulse generated once for each revolution of the rotating part with vibration of the vehicle frame. A portable instrument was developed and tested on a single rear axle truck with simulated faults (weights added to the wheels or drive shaft). The results showed that the cause of some power train faults -- e.g., driveline misalignment, drive-shaft unbalance, or front vs rear wheel unbalance -- can be readily diagnosed by this technique. Moreover, this technique does not require expensive or sophisticated equipment [79].

A high frequency vibration technique similar to that used to determine the condition of gears and bearings has been used to monitor the condition of the power trains of two crawler tractors [80]. Vibration signatures were matched to mechanical defects. The goals of the investigation were to determine if a simple diagnostic system could be built and if one system could be built and used to diagnose the cause of faults in the power trains of several vehicles. A diagnostic system was built, but the tractors were not available for teardown and inspection of the power train for wear. The diagnostic system involves bandpass filtering in one frequency range so that it is applicable to different tractors [80].

Data processing techniques [50] were used to process vibration data measured on an internal combustion engine. Processing included computing a variance analysis to identify periodic components of vibration in the engine and digital filtering to identify periodic components in the intake manifold pressure spectrum of the engine. Changing variances is another technique used to identify rotational locked periodic vibration components in an internal combustion engine [51].

Various Non Destructive Testing techniques have been proposed for inspecting tires and predicting their dynamic performance. A study was undertaken to determine the feasibility of tire resonances as indicators of hidden defects that might lead to failure [81]. A resonance frequency is excited at the center of the tread; defects are indicated when unbalance occurs in signals from the two transducers on the sidewalls. The detectability of defects ranged from poor to very good and depended on the type of defect, its size, and its location. The ultimate goal is to develop a system that can be used to inspect tires mounted on vehicles [81].

A nondestructive technique for inspecting railroad car wheels on the car has been investigated in the laboratory [82]. The car wheel is excited into vibration by

impact; the sound emitted is analyzed to determine the vibration signature. Good wheels and flawed wheels exhibit different signatures; a flawed wheel is detected by comparing its spectrum to a standard spectrum of a good wheel [82].

QUALITY ASSURANCE

Loose parts and free objects in electronic assemblies are often undetected in normal inspections and performance tests. Mechanical signature analysis has been used to screen electronic assemblies for loose particles weighing as little as one milligram, bouncing on the bottom of the case [83]. Weak bonds between a ceramic substrate and the case of a microelectronics package have also been detected [84]. In this case the excitation is applied externally (Figure 2).

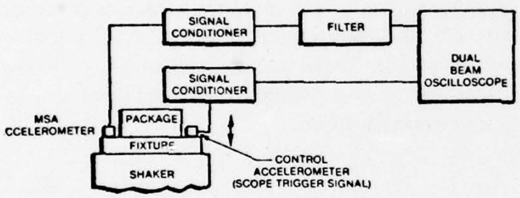

Figure 2. Mechanical Signature Analysis Test Setup for Quality Assurance Applications

Mechanical signature analysis has also been used to inspect bearings for defects prior to installation in assemblies [84, 85]. A mechanical signature analysis study was conducted on aircraft hydraulic pumps. Operating limits on the mechanical signatures were used as indicators of mechanical quality during production acceptance tests. Vibration signature data were obtained on good pumps and defective pumps operating at several flow conditions and speed settings. Vibration signatures of defective pumps differed significantly from those of good pumps [86].

USER EXPERIENCE

Mechanical signature analysis is being used to monitor the condition of rotating machinery on ships [20]. A digital computer-controlled monitoring system capable of monitoring machinery under different operating conditions was tested on a cargo ship. However, this system does not provide data that can be used to immediately diagnose the cause of a problem [20].

The Canadian Armed Forces use mechanical signature analysis to check the quality of repairs and overhauls of machinery as well to perform acceptance tests on new machinery. They have found that octave band analysis is sufficient to define the nature of many problems although it is not sensitive enough to identify the defective element [21].

The United States Navy has used mechanical signature analysis on selected pieces of surface ship machinery to identify those in need of overhaul. Experience has shown that less than 20% of the equipment scheduled for repair or overhaul required it. Also faults in shipboard machinery have been ranked according to the ease with which they can be diagnosed with mechanical signature analysis [87].

Mechanical signature analysis can also be used to monitor the condition of shipboard diesel engines and their auxiliaries even though the engines are slow speed and their frequencies are often below the lowest cutoff frequencies of available instrumentation. Nevertheless, the condition of both the engine and its auxiliaries are monitored because failures in some auxiliaries can cause failure in the main engine [88].

A diagnostic system was developed for a gas turbine on a military aircraft. This system uses vibration signatures and other measurements to indicate faults [89]. Mechanical signature analysis is also used as the basis of an automatic diagnostic system for commercial jet-powered helicopters. (Most of the major mishaps to helicopters can be attributed to faults in either the engine or the transmission.) Requirements for such a system differ somewhat from those of a ground system; for example, condition prognosis is not needed, and the system must be inexpensive and easy to operate. The potential savings of a simple basic system have been demonstrated; it was felt that such a system could pay for itself in one year [90].

The petrochemical industry has had extensive experience with mechanical signature analysis for monitoring the condition of many types of rotating ma-

chinery. A pilot system in a chemical plant showed that it is possible to use on-stream vibration measurements to detect small defects in bearings or gears, loose parts, or faulty operation [91]. In another chemical plant, 37 potentially serious problems in components of rotating machinery were found by measuring mechanical signatures [92].

One refinery achieved significant cost savings when they established a machinery surveillance and diagnostic program. Unscheduled shutdowns due to catastrophic failures were reduced, running time of machinery was extended, and the need to tear down and inspect machinery was reduced. The scope of the program grew from measuring unfiltered bearing cap vibration levels on a few components of minor machinery to measuring vibration signatures on all machines and the use of sophisticated instrumentation to diagnose faults [93]. An updated report [94] describes the refinery's total approach to mechanical inspection of rotating machinery; this approach applied to all machinery. Measurements included shaft orbit, axial shaft position, radial shaft position, bearing cap vibration, and case vibration measurements. Since the start of the rotating machinery monitoring program, a 30% cost saving in maintenance has been realized. The same program was extended to reciprocating machinery with even greater savings [94].

Neither of the two experiences described above involved computers. Installation of a real-time minicomputer-based machinery monitoring system in a chemical plant yielded a 100% return on the investment in one year. The system measures trend and stores measurements of many parameters, thus providing insight into the vibration of the equipment. The system uses off the shelf hardware and has been highly reliable [95].

A computer-aided system for monitoring rotating machinery in another chemical plant was also successful [96]. The system was used solely for on-stream condition monitoring of critical machinery, not for start-up of new machinery. The computer system in combination with a real time analyzer can generate many types of frequency spectra, log data, and display shaft or bearing orbits. Since the system has been in operation, few repairs have had to be made to the computer or to the monitor circuit boards [96]. A combination real time analyzer and minicomputer for analysis of machinery vibration data has been justified in one case because the system is more flexible both as a diagnostic tool and for condition monitoring [97].

The final issue is the cost of mechanical signature analysis for monitoring machinery or system condition. The potential payoff of monitoring machinery condition has been demonstrated by users who have found it cost effective; monitoring has also prevented costly unscheduled outages.

Noncontact shaft position monitoring instruments are typically more expensive than bearing cap or casing vibration instruments; however, the costs of signal conditioning equipment, data processing equipment, readout equipment, and any specialized measuring instruments must be added to these costs for the total cost of a system. Many monitoring systems are expensive because of duplication of instrumentation, minicomputers, and relatively expensive sensors. Mitchell [98] has suggested programmed microprocessors to scan individual channel outputs for limit conditions as one possibility for reducing the cost of monitoring systems.

CONCLUSION

There are many techniques for exploiting the vibration signatures of machinery or systems to determine their condition or to diagnose the cause of faults. Although rotating machinery, or systems that generate vibration signatures as a result of their operation, have been stressed in this article, there is no limit to the potential applications except the ability to generate a vibration signature and perhaps some imagination. Many applications exist and many mechanical signature analysis techniques are available; there is no single best technique. The best technique depends on the application. In most cases mechanical signature analysis alone is sensitive enough to indicate the condition of a system, but, in a few cases, measurements of performance or operating parameters might also be necessary to indicate the condition of a system or to provide complete protection. Nevertheless, mechanical signature analysis is a viable technique; laboratory studies and field experience have shown that the vibration in a system or its components can be related to defects or the severity of wear. Finally,

the published literature on user experience has shown that the analysis is cost effective and can be used to warn of possible catastrophic failures.

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DAMPING IN STRUCTURAL JOINTS

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Abstract - The frictional damping mechanisms that can occur in structural joints are discussed. Linearized theories appear adequate for describing the macro-slip range. Optimum joint clamping forces exist for maximum energy dissipation and for minimum structural response and have been experimentally confirmed. Fretting corrosion can be controlled by hardening joint interfaces or using EDM joints. It is suggested that some joints in any structure could allow slight slip without affecting the integrity of the structure, thereby increasing inherent damping and improving vibrational performance.

All structures must have sufficient damping to keep vibration response, dynamic stress levels, noise, and fatigue within acceptable limits. Unfortunately, because of the low mass and all-welded construction methods now used, many present-day structures lack sufficient inherent damping; damping devices are thus necessary. Such devices may require expensive high-damping alloys or frequency- and temperature-sensitive viscoelastic layers [1, 2]. Because about 90% of the total damping in a structure originates in the joints, it would seem reasonable to increase such damping, thereby making inherent damping sufficient and eliminating the need for expensive and complex damping devices.

Although joint damping has been recognized for many years, it has not been used because of the possibility of fretting corrosion and stiffness non-linearity and loss unless joints are very tightly clamped. In addition, friction forces in the joint are non-linear, and the joint is therefore difficult to analyze.

Some flexibility must be allowed in a joint designed to dissipate maximum vibrational energy by interfacial slip, but, if the joint is carefully located, it need not affect the integrity of the structure. That is to say, some, but not all, structural joints could allow slight interfacial slip and therefore frictional damping, adding to the inherent damping of the structure. Furthermore, the undesirable side effects of frictional damping have received serious study, so that optimization, or at least control, of frictional damping in real structures is now possible.

FRICTIONAL DAMPING

Energy dissipation in a dry joint is a complex process involving several mechanisms the relative significance of which depends on joint conditions. When a tangential force is applied to a clamped joint, the effects depend on the depth of penetration of the asperities into the opposing surface. Elastic deformation takes place at the points that just touch; the asperities lose contact and give rise to sound. Those elements that penetrate to a greater depth are deformed: strong interpenetrating asperities give rise to shear and considerable surface damage [3-9].

Energy dissipation in a joint is influenced by interfacial pressure [10-19]

- macro-slip: at low joint clamping pressures, sliding on a macroscale takes place. Coulomb's law of friction is assumed to hold.

- micro-slip: if the joint clamping pressure increases, mutual embedding of the surfaces occurs. Sliding on a macroscale is reduced and micro-slip is initiated. Very small displacements of asperities relative to their opposite surfaces occur.

- plastic deformation: a further increase in the joint clamping pressure causes greater penetration of asperities. The pressure on the contact areas equals the yield pressure of the softer material. Relative motion causes further plastic deformation of the asperities.

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In most joints, all of these mechanisms operate; their relative significance depends on joint conditions. In joints with high normal interfacial pressures and relatively rough surfaces, for example, plastic deformation is significant. Many joints have to carry pressures of this magnitude to satisfy such criteria as high static stiffness. A low normal interface pressure would tend to increase the significance of the slip mechanisms, as would an improvement in the quality of the surfaces in contact. The damping capacity of a lap-joint subjected to partial slip has been shown to be a maximum when force transference is by friction throughout the joint. With macro-slip, energy dissipation is proportional to the product of the interface shear force and the relative tangential motion. Under high pressure, the slip is small; under low pressure the shear force is small. Between the two extremes the product is a maximum [20].

When two surfaces nominally at rest with respect to each are subjected to slight vibrational slip, fretting corrosion can be initiated. This particularly serious form of wear is inseparable from energy dissipation by interfacial slip and hence frictional damping [21, 22].

THEORY

Dissipation of energy by interfacial slip in joints is complex. Any theoretical assessment requires a value for the coefficient of friction μ, either an average value or the actual value during the cycle. Because of the practical variations in μ, theoretical results are often expressed in terms of the tangential force at the joint interface. Thus, if only the clamping force is known, theoretical predictions are qualitative.

It is generally accepted that the friction force generated between joint interfaces is usually [23-26]

- dependent on the materials in contact and their surface preparation
- proportional to the normal force across the interface
- substantially independent of the sliding speed and apparent area of contact
- greater just prior to relative motion than during uniform relative motion

The equations of motion of a structure with friction damping are thus nonlinear; in most analyses equations are linearized in some way [27-33]. One useful approach is to calculate an equivalent viscous damping coefficient such that the energy dissipated by friction and viscous dampers is the same. This has been shown [34] to give an acceptable qualitative analysis for macro-slip. A modification of this method involves replacing μ by a term that allows for changes in the coefficient with slip amplitude [31]. Some success has also been obtained [20] by simply replacing the friction force with an equivalent harmonic force which is, essentially, the first term of the Fourier series representing the friction force. For laminated plate vibration, the interfacial friction force has been identified with the in-plane force intensity [35].

Techniques for linearizing the friction force appear to be adequate because of the uncertainty in the value of μ.

DAMPING EFFECTS

Energy Dissipation

Energy dissipation in both rotary (moment loaded) and lap (force loaded)-joints under micro-slip conditions has been measured [36]. The efficiency of the joint in dissipating energy is taken as the actual energy loss compared with the maximum possible loss. It has been shown that the joint efficiency has a maximum of 3/4 for the rotary joint but only 1/3 for the lap-joint. However, for both joints, macro-slip is recommended for high energy dissipation.

Under macro-slip conditions energy losses capable of providing large reductions in resonant stresses can be achieved [20]. To achieve maximum energy loss joints must be designed so that a particular value of clamping force is maintained at the interface; for maximum energy loss, the clamping force is one half the value required to just prevent macro-slip. The amplitude of slip under these conditions is one half the amplitude for zero clamping force. This indicates a simple practical method for adjusting a joint to provide maximum energy dissipation. However, these results were obtained using an interface pressure of 0.7 MN/m^2 for maximum energy dissipation; such low pressures are not likely to be found in many structural joints. Higher clamping forces reduces the slip and energy dissipation [37-43].

Structural Response

Several investigations into the vibration response of structures with controlled frictional damping in the joints have been reported [44-53]. For example, investigations have been carried out [34] on the effects of frictional damping on the amplitude-frequency response of a beam mounted on stiff elastic supports at each end. This was considered to be a model of a general structural member. Provision was made at both ends of the beam for introducing frictional damping by interfacial slip. The extreme zero frictional damping conditions obtained by zero force and zero slip gave the beam different resonant frequencies. By adjusting the joint clamping forces to an optimum value, the beam response could be minimized over a wide frequency range. This facility for changing structural resonances by controlling joint stiffness is extremely useful. Furthermore, the clamping forces for minimum amplitude-frequency response are much greater than those associated with maximum energy dissipation, which results in high structural stiffness. A linearized analysis gave good qualitative agreement between theory and experiment. The friction force occurring in the joint for minimum resonant amplitude response was independent of the beam support stiffness and damper support stiffness, although the latter should be as high as possible.

Frictional damping obtained in a bolted joint allowed to slip in rotation but not in translation -- so that little structural static stiffness was sacrificed -- has also been studied [44]. This situation is found in many iatticed framework structures, where translational slip in a joint is not practical but rotational slip is. A rectangular frame with a single diagonal strut, one joint of which was bolted and could provide frictional damping by rotational slip was studied; an optimum bolt torque existed for minimum resonant response, and the resonant frequencies could be controlled. Furthermore, the reduction in the major resonant mobility (up to 11 dB) was of the same order of magnitude as the reductions reported by others dealing with joints that slip only in translation. Good qualtitative agreement between theory and experiment was obtained by assuming the friction torque to be harmonic, hence linearizing the analysis.

Increasing structural damping with laminated panels has also been proposed [35]. In this case, a panel of thickness h is replaced by a number of laminates of total thickness h. The laminates are bolted or riveted together, so that, as the panel vibrates, interfacial slip occurs between the laminates, giving rise to frictional damping. A freely supported laminated circular plate was produced by clamping two identical plates together to form a plate subjected to interfacial friction forces. The resulting severe static stiffness penalty is often not important in panels. Under optimum clamping conditions, a Q factor of 20 was achieved compared to a value of 1,300 found for a solid plate. A wide range of clamping forces gave near-optimum conditions of minimum vibration amplitude at the first mode resonance. The theoretical investigation considered the laminated plate as a single plate subjected to in-plane forces with which the interfacial frictional forces of the laminated plate were identified. Good qualitative agreement between theory and experiment was found.

SURFACE DAMAGE

The methods by which fretting can be controlled are extremely varied and depend largely on the complexity of a particular problem. In some cases, movement has been encouraged with a low coefficient of friction; in others movement has been minimized by a high coefficient. Fretting damage can be minimized by providing a layer of low modulus or yield strength between the joint interfaces. Relative motion is taken up within the layer, but the layer does get squeezed out from between the mating surfaces, an effect which is also found with lubricants. Relative sliding can be encouraged by using nonmetallic coatings that provide a low coefficient of friction. They function also to prevent intermetallic contact and thus inhibit the formation of micro-welds during the early stages of fretting. Resin-bonded surface coatings or plastic skins have only moderate strength, however, so that asperities on the joint interfaces tend to break through the protective layer.

Metal coatings have been recommended for reducing fretting corrosion; they promote seizure of the contacting surfaces or even to act as a lubricant. Metal sprayed on the joint interfaces will also prevent contact between them, so that, if fretting occurs, any cracks formed propagate only within the sprayed

metal. In tests in which a simple lap-joint was clamped together while one element was subjected to a harmonic excitation, thereby creating relative slip at the joint interfaces, surfaces that have been shot-peened, blasted, and metal sprayed show some reduction in fretting corrosion. However, the common and inexpensive treatment involving cyanide hardening has been suitable because surface damage is slight and energy dissipation capabilities of the joint are maintained. It has also been shown that electro-discharge machined joints have high static and dynamic stiffness and possess up to 100% more damping capacity than ground joints; surface damage due to fretting corrosion can be reduced by an order of magnitude [54-63].

CONCLUSIONS

Of the several motions that occur in a dry joint subjected to variable shear forces, relative macro-slip between the joint interfaces in the plane of the joint provides the greatest damping. An optimum clamping force exists under which the joint dissipates maximum vibrational energy; a different clamping force may be necessary to minimize the vibration response of a structure.

The various attempts at theoretical descriptions of frictional damping in joints rely on a linearization of the friction force. Useful qualitative predictions have been made; they are acceptable because of the uncertainty with which the value of μ throughout a cycle can be determined.

Fretting corrosion can be greatly reduced by hardening the joint interfaces or by using EDM joints. Furthermore, the damping capacity of a joint can be increased by these surface treatments, although some adjustment to the clamping force may be necessary for optimum conditions because of a change in μ.

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BOOK REVIEWS

SOUND, NOISE AND VIBRATION CONTROL

L.F. Yerges
Van Nostrand Reinhold Co., New York, NY, 1978

This book represents a second edition of a handbook that was first published in 1969. The author has set out to write a book as "a working guide for the professional," as a "cookbook." In this book he intends to represent "distillation of a lifetime of experience in the field of acoustics." The book seems to contain a lot of useful information, most of it presented in a very clear fashion and in such a way that the reasons why are less important than the discussion of what is. The material in the previous edition does not seem to have been revised; rather, substantial new information has been added. The new information concentrates on sound fields and sound enclosures, tests and measurements, and case histories of industrial noise control. As with the material from the old edition, the new material seems to be clearly written, although brief in style; emphasis is on results. Thus, for example, the section on sound fields contains the formulas by which one can calculate sound pressure level from sound power level in nonreverberant space.

Much information is presented not in formulas but in discursive discussion that appears to be based on the author's experience; e.g., his discussion of industrial noise sources. After he lists seven major sources of industrial noise, including jets, cutting and grinding processes, and flames, Yerges goes on to say that a particularly unnecessary noise source in industry is the cheap and almost unintelligible paging system. He discusses noise control at the source, along the path, and at the receiver.

The new section on tests and measurements designates four principal laboratory tests, describes in moderate detail two tests of building component performance that are generally done in the field, and then lists 13 suggestions and caveats that comprise useful recommendations when data is taken in the field. These 13 suggestions obviously reflect much field measurement experience, and in the author's experience they do provide a good check list for taking and recording field data.

The final section added to this edition, that on industrial noise case histories, presents some ten case histories in about as many pages. In each case the author presents a one-line description of the noise source, a very short description of the problem, a brief description of the solution highlighted by a figure that shows the recommended enclosure or barrier, and a brief summary of the result. There is not enough hard data given in these case histories to provide anything in the way of real insight. However, as discursive and brief representations of solutions, they do provide some indication of the kinds of options that might be attractive or suggestive to the noise control engineer in the field.

In summary, the second edition of Yerges' book seems to represent a useful compilation of some data, most of which is present in the first edition, and a clear if simple discussion of the application of elementary principles to noise control problems. This is certainly not a textbook. And, although the author very specifically states that he is writing a cookbook (and here he has succeeded reasonably well), it is disturbing to read a book that is based in part "on the premise that few people find the subject of acoustics of compelling interest," and wherein "every attempt has been made in this book to avoid scholarly language." It is true, as the author says, that the principles of acoustics are "simple and clear." However, their application in industry is not so straightforward as the author would like to have us believe. The problem with any cookbook is, of course, that it does not provide sufficient foundation

for the reader to go on to learn on his own. In this respect, Yerges' book fails, as do all other handbooks of this genre.

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FINITE ELEMENT ANALYSIS IN FLUID DYNAMICS

T.J. Chung
McGraw-Hill, 1978

This book is an excellent contribution to the literature on finite element analysis. Previous texts in which finite elements have been applied to fluid dynamics problems have limited the treatment to a chapter or two while concentrating mainly on structural applications. Of course, this is because the finite element method has been applied to fluid mechanics only for a short time compared to the state of development for solid mechanics areas, in which the method has been used for approximately 25 years. Other texts on finite element analysis for fluid dynamics have been either proceedings of a symposium or contributed articles by a wide variety of authors. Both of these types of text suffer from lack of continuity. Finite Element Analysis in Fluid Dynamics has no such problems.

As stated by the author, the material in the text is for graduate level students or advanced industrial applications. Both theoretical development and applications to specific problems in fluid dynamics are excellent. A short outline of the contents will be helpful to potential users.

Chapter 1 contains mathematical preliminaries to the development of a finite element method. Both variational and residual methods are treated. It is of interest that the direct method employed in virtually all finite element texts for structural applications is not considered. Due to the nature of the differential equations governing fluid mechanics, the variational method is appropriate for some problems but not others. The use of one form of the method of weighted residuals is essential for solving problems for which no variational principle exist. The Galerkin residual technique described in this text is widely used because it reduces to the same equations as the variational technique if a variational principal can be found for that problem. Chapter 1 considers such relatively advanced mathematical concepts as functional analysis, Sobolev spaces and Hilbert spaces; it includes some simple one-dimensional examples.

Chapter 2 includes element interpolation functions in one, two, and three dimensions. Linear interpolation functions as well as higher order polynomials are considered for various types of elements. No example problems are presented.

Chapter 3 describes the solution and accuracy of finite element equations in a mathematical sense. Standard methods for assembling element properties into global equations for the nodal unknown field variables are presented. Treatments include elliptic, parabolic, and hyperbolic differential equations.

Chapter 4 develops the equations of fluid mechanics from a general point of view. Tensor notation is used to reduce the size of the equations and should be appropriate because users of this text should be familiar with the equations of fluid flow before attempting the technique.

Incompressible flow problems are discussed in Chapter 5. Two-dimensional inviscid flow problems are considered first. Triangular elements with linear interpolation functions are used to model two-dimensional flow around a circular cylinder. Both the stream function formulation and velocity potential formulation are employed. Details of both solutions are nicely shown and the results compared to analytical solutions. An error analysis illustrates the principles first introduced in Chapter 3. Axisymmetric inviscid flow is considered next; isoparametric elements are used in the solution. In the discussion of incompressible viscous flow, both the velocity-pressure formulation and stream function formulation are examined. The method of weighted residuals is used to formulate the finite element approach. Wave motion in shell basins, rotational flow, boundary layer flow, and flow with boundary singularities are considered. Unfortunately, only a few examples are given, and then only the results

of the approach are presented. The details of the solution technique are not covered in detail. Some solutions for problems with both finite elements and finite differences are compared.

Chapter 6 considers compressible flow problems. Viscous compressible flow is illustrated with an example for the boundary layer behind a normal shock wave. For inviscid compressible flow a nice comparison is given between the residual approach and the variational technique. Transonic aerodynamics is also considered.

Chapter 7 introduces applications to such special topics as diffusion, magneto-hydrodynamics, and varified gas dynamics. As would be expected, these topics are not considered in depth.

The appendix includes a computer program for two-dimensional flow around a cylinder with triangular elements using the stream function formulation, two-dimensional flow around a cylinder with isoparametric elements using the velocity potential, and an axi-symmetric ideal flow around a sphere with isoparametric elements using the stream function formulation. No specific information is given on the input and output format for these computer programs.

In summary, this book is a valuable but somewhat advanced theoretical treatment of techniques for applying finite elements to fluid mechanics problems. Because it is at a relatively advanced level, the book may not be useful to readers without a finite element background. It is, however, a comprehensive treatment and represents the state of the art in finite elements for fluid dynamics.

P.E. Allaire
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COMPUTER METHODS FOR MATHEMATICAL COMPUTATIONS

G.E. Forsythe et al.
Englewood Cliffs, NJ, Prentice-Hall, Inc., 1977

The text should be of interest to those interested in using methods of numerical analysis to solve problems rather than designing the numerical algorithms themselves. Included in the book are a number of FORTRAN subroutines for

- solving sets of linear equations
- cubic spline fit
- numerical integration using Newton-Cotes formula
- Runge Kutta method
- solution of nonlinear equations
- locating one-dimensional minimum
- finding eigenvalues using determinant search
- generating random numbers

The text is almost a manual in which are described use of subroutines to solve meaningful problems. The reader is assumed to have a background in differential and integral equations and to have some facility with FORTRAN.

The book is organized into sections which are appropriate for the class of numerical problems associated with the subroutines including:

- discussion of floating point computation
- linear systems of equation
- interpolation
- numerical integration
- initial value problems in ODEs
- solution of nonlinear equations
- optimization
- least squares and singular value decomposition
- random number generation

This book should provide a valuable insight to the user of such large computational systems as MSC/NASTRAN, ANSYS, and STARDYNE, which incor-

porate the general type of numerical analysis capability described. This class of reader will find the discussion of such topics as roundoff error, truncation error, conditioning numbers, matrix decomposition, and the theory of spline fits enlightening. A discussion of Gaus integration rather than Simpson's rule would have been meaningful, especially for those involved in modeling using the finite element method.

The book is a welcome addition to the literature on numerical analysis.

H.G. Schaeffer
Schaeffer Analysis
Kendall Hill Road
Mont Vernon, New Hampshire 03057

SHORT COURSES

SEPTEMBER

FLOW-INDUCED VIBRATION PROBLEMS AND THEIR SOLUTIONS IN PRACTICAL APPLICATIONS: TURBOMACHINERY, HEAT EXCHANGERS AND NUCLEAR REACTORS

Dates: September 17-21, 1979
Place: The University of Tennessee Space Inst.
Objective: The aim of the course is to provide practicing engineers engaged in design, research and service, an in-depth background and exposure to various problems and solution techniques developed in recent years. Topics to be covered are: the fundamental principles of unsteady fluid flow, structural vibration and their interplay; review of the morphology of flow-induced vibration; state-of-the-art discussion upon theory, experimental techniques and their interaction; and methodology of alleviation.

Contact: Jules Bernard, The University of Tennessee Space Institute, Tullahoma, TN 37388 - (615) 455-0631.

ROTATING MACHINERY VIBRATIONS SEMINAR

Dates: September 18-20, 1979
Place: Boxborough, Massachusetts
Objective: This seminar will feature lectures on fluid film bearings, torque induced lateral vibration, coupling use of rotating machinery, minicomputer use and self-excited vibrations in rotating machinery. Practical aspects of rotating machines will be emphasized.

Contact: Dr. Ronald L. Eshleman, Vibration Institute, Suite 206, 101 West 55th St., Clarendon Hills, IL 60514 - (312) 654-2254/654-2053.

DIGITAL SIGNAL PROCESSING

Dates: September 18-20, 1979
Place: Washington, D.C.
Objective: This seminar covers theory, operation and applications -- plus additional capabilities such as transient capture, amplitude probability, cross spectrum, cross correlation, convolution coherence, coherent output power, signal averaging and demonstrations.

Contact: Spectral Dynamics Corp. of San Diego, P.O. Box 671, San Diego, CA 92112 - (714) 268-7100.

DIAGNOSING ROTATING MACHINERY VIBRATION PROBLEMS

Dates: September 18-21, 1979
Place: Santa Clara, California
Dates: October 2-5, 1979
Place: Boston, Massachusetts
Dates: October 16-19, 1979
Place: Chicago, Illinois
Dates: October 30-November 2, 1979
Place: Houston, Texas
Objective: This seminar is designed to provide both an overview of machine vibration characteristics and diagnostic techniques and an in-depth examination of several solved machine vibration problems. Topics include the fundamental causes of machine vibration, determining component and structural frequencies, considerations for setting up a preventive maintenance program (such as machine failure characteristics, diagnostic technique effectiveness, thresholds, and criteria), and monitoring equipment operation and usage. Industrial consultants and university experts will be featured at each seminar to provide a detailed discussion of illustrative case histories and to suggest advanced diagnostic techniques to solve vibration problems.

Contact: John Sramek, GenRad, Inc., 2855 Bowers Ave., Santa Clara, CA 95051 - (408) 985-0700, Ext. 267.

INDUSTRIAL AND MACHINERY NOISE CONTROL PRACTICE

Dates: September 23-27, 1979
Place: Institute of Sound and Vibration Re-

search, The University, Southampton, UK
Objective: The course is aimed at informing practical engineers on how machines make noise and how this can be controlled at both the design and installation stages. Methods of standard testing, the exact nature of national legislation and the effects of factory layout are all covered. An important aspect of the course is the inclusion of applications of noise control techniques to reciprocating engines, presses, forges, textile machines, compressors, valves, pile drivers, etc.

Contact: Mrs. O.G. Hyde, ISVR Conference Secretary, The University, Southampton, S09 5NH, UK - (0703) 559122, Ext. 2310 or 752, Telex 47661.

UNDERWATER ACOUSTICS
Dates: September 24-28, 1979
Place: Pennsylvania State University
Objective: This short course is structured so that those attending have a choice between a basic or an advanced set of lectures during the first day and a half. Therefore it can serve as an introductory course for those who are new to the field but who have a good educational background in physics, mathematics, or some related branch of engineering; or as a refresher course for those scientists and engineers currently practicing in the underwater acoustics field. The material includes the linear and nonlinear propagation of sound in the ocean, transducers, and sources of underwater noise.

Contact: Robert E. Beam, Conference Coordinator, The Pennsylvania State University, Keller Conference Center, University Park, PA 16802 - (814) 865-5141.

OCTOBER

SONAR AND SEISMIC SIGNAL PROCESSING
Dates: October 1-5, 1979
Place: Pennsylvania State University
Objective: This course is designed to provide those scientists and engineers practicing in the fields of underwater acoustics or seismic exploration with an understanding of the principles and techniques used for the detection of underwater and underground signals. To obtain maximum benefit from the course, participants should already be familiar with the basics of Fourier transform theory and the more common probability distributions.

Contact: Robert E. Beam, Conference Coordinator, The Pennsylvania State University, Keller Conference Center, University Park, PA 16802 - (814) 865-5141.

AN INTRODUCTION TO VIBRATION AND SHOCK SURVIVABILITY, TESTING, MEASUREMENT, ANALYSIS AND CALIBRATION
Dates: October 1-5, 1979
Place: Southampton, England
Objective: Topics to be covered are resonance and fragility phenomena, and environmental vibration and shock measurement and analysis, also vibration and shock environmental testing to prove survivability. This course will concentrate upon equipments and techniques, rather than upon mathematics and theory.

Contact: James E. Frost, Plessey Assessment Services, Ltd., Titchfield, Fareham, Hampshire PO14 4QA, UK - (03294) 43031 or Wayne Tustin, 22 East Los Olivos St., Santa Barbara, CA 93105 - (805) 682-7171.

VIBRATION CONTROL
Dates: October 8-12, 1979
Place: The Pennsylvania State University
Objective: The seminar will be of interest and value to engineers and scientists in industry, government, and education. Topics include dynamic mechanical properties of viscoelastic materials; structural damping; isolation of machinery vibration from rigid and nonrigid substructures; isolation if impact transients; reduction of vibration in beams, plates, and shells; reduction of the flow-induced vibration of complex structures; case histories in vibration reduction; and characteristics of multi-resonant vibrators.

Contact: Professor John C. Snowdon, Seminar Chairman, Applied Research Lab., The Pennsylvania State University, P.O. Box 30, State College, PA 16801 - (814) 865-6364.

NOISE CONTROL IN MACHINES

Dates: October 22-25, 1979

Place: The Pennsylvania State University

Objective: This seminar emphasizes the design of quiet equipment and noise reduction methods, such as mufflers and enclosures to meet current and projected federal regulations. All three aspects of machinery noise are covered: the nature and prediction of noise sources such as fans, compressors, jets, control valves, and vibrating surfaces; the propagation of sound through simple and complex walls and enclosures, as well as propagation in the out-of-doors; and the response of the receiver - the human being in the working or living environment in both physiological and psychological terms. The course also covers hands-on experience using the latest acoustical data acquisition and processing equipment.

Contact: David K. Furchner, The Pennsylvania State University, Radnor Campus - Continuing Education, 259 Radnor-Chester Rd., Radnor, PA 19087 - (215) 293-9860.

MACHINERY VIBRATIONS SEMINAR

Dates: October 23-25, 1979

Place: Mechanical Technology Inc., Latham, NY

Objective: To cover the basic aspects of rotor-bearing system dynamics. The course will provide a fundamental understanding of rotating machinery vibrations; an awareness of available tools and techniques for the analysis and diagnosis of rotor vibration problems; and an appreciation of how these techniques are applied to correct vibration problems. Technical personnel who will benefit most from this course are those concerned with the rotor dynamics evaluation of motors, pumps, turbines, compressors, gearing, shafting, couplings, and similar mechanical equipment. The attendee should possess an engineering degree with some understanding of mechanics of materials and vibration theory. Appropriate job functions include machinery designers; and plant, manufacturing, or service engineers.

Contact: Mr. Paul Babson, MTI, 968 Albany-Shaker Rd., Latham, NY 12110 - (518) 785-2371.

MACHINERY VIBRATION ANALYSIS

Dates: October 23-25, 1979

Place: Seattle, Washington

Objective: New techniques for measuring and analyzing vibration in rotating machinery will be covered. The seminar will feature hands-on time with the latest instrumentation used in advanced machinery maintenance. Machinery models and taped data from industrial process machinery will be used for realistic demonstrations of pinpointing the source of vibration and measuring its exact intensity and frequency. Also discussed will be hot alignment of coupled machines, field balancing of high-speed turbines, round-the-clock vibration monitoring systems, and managing vibration data by computer.

Contact: Bob Kiefer, Spectral Dynamics, P.O. Box 671, San Diego, CA 92112 - (714) 268-7192.

ROTATING MACHINERY VIBRATIONS COURSE

Dates: October 29-November 1, 1979

Place: Cherry Hill, New Jersey

Objective: This advanced course on rotating machinery vibrations will cover physical/mathematical modeling, mathematical computations, physical descriptions of vibration parameters, measuring, and analysis. Machinery vibrations control techniques will be discussed. Torsional vibration measurement, analysis, and control will be reviewed.

Contact: Dr. Ronald L. Eshleman, Vibration Institute, Suite 206, 101 West 55th St., Clarendon Hills, IL 60514 - (312) 654-2254/654-2053.

NOVEMBER

VIBRATION DAMPING

Dates: November 5-8, 1979

Place: University of Dayton Research Institute

Objective: Topics to be covered are: damping behavior of materials, response measurements of damped systems, surface damping treatments on vibrating members, discrete damping devices, special analytical problems, increasing linear viscoelastic material properties, damping of acoustic vibrations, selected case histories, problem solving sessions, and demonstration of digital fast fourier analyses.

Contact: Mrs. Audrey G. Sachs, University of Dayton Research Institute, Dayton, OH 45469 - (513) 229-2919.

DYNAMIC ANALYSIS WORKSHOP

Dates: November 5-9, 1979
Place: San Diego, California
Objective: This course will cover the latest techniques of analyzing noise and vibration in rotating machinery and power-driven structures. The workshop will cover both the theory and practical aspects of tracking down malfunctions and preventing failures caused by unbalance, misalignment, wear, oil whirl, etc. Included in the course will be demonstrations and practical, hands-on experience with the latest noise and vibration instrumentation; Real Time Analyzers, FFT Processors, Transfer Function Analyzers and Computer-Controlled Modal Analysis Systems. Actual case histories and specific machinery signatures will be discussed.

Contact: Spectral Dynamics Training Manager, P.O. Box 671, San Diego, CA 92112 - (714) 565-8211.

VIBRATION AND SHOCK SURVIVABILITY, TESTING, MEASUREMENT, ANALYSIS, AND CALIBRATION

Dates: November 5-9, 1979
Place: Arlington, Virginia
Dates: December 10-14, 1979
Place: Ling Electronics, Anaheim, California
Objective: Topics to be covered are resonance and fragility phenomena, and environmental vibration and shock measurement and analysis, also vibration and shock environmental testing to prove survivability. This course will concentrate upon equipments and techniques, rather than upon mathematics and theory.

Contact: Wayne Tustin, 22 East Los Olivos St., Santa Barbara, CA 93105 - (815) 682-7171.

THE APPLICATION OF VIBRATION MEASUREMENT AND ANALYSIS IN MACHINE MAINTENANCE

Dates: November 6-8, 1979
Place: New York, New York
Dates: November 13-15, 1979
Place: Dallas, Texas
Objective: These sessions are designed to give an understanding of the concept of using machinery vibration as a means of detecting wear in rotating parts, and of predicting machinery breakdowns. It will deal with the principles and methods of machine condition analysis and the economic benefits obtainable from condition monitoring. Fundamentals of vibration measurement and analysis are explained with particular reference to optimum choice of measurement parameter and techniques to avoid unnecessary errors and limitations in detection and diagnostic capability.

Contact: B&K Instruments, Inc., Bruel & Kjaer Precision Instruments, 5111 W. 164th St., Cleveland, OH 44142.

CONTROLLING THE EFFECTS OF PULSATIONS AND FLUID TRANSIENTS IN PIPING SYSTEMS

Dates: November 7-9, 1979
Place: San Antonio, Texas
Objective: The seminar will cover various means for preventing and controlling the detrimental effects of pulsations and fluid transients on piping, pumps, compressors, and other plant systems and equipment. Topics will include: pulsation generation mechanisms and their effects in plant piping and equipment; the SGA Compressor Installation Simulator (SGA Analog) and its applications; pulsation control and piping system design; mechanical response of plant components to pulsations and transient excitation; vibration control in piping systems; vibration-induced stress and meaningful stress criteria; transient fluid interaction of system components (flow instabilities, cavitation, flashing, piping effects on surge, etc.); effects and control of pulsations in flow measurement; and pulsation effects on the performance of compressor/pump installations.

Contact: Joe L. Gulinson, Southwest Research Institute, P.O. Drawer 28510, San Antonio, TX 78284 - (512) 684-5111, Ext. 2521.

THE 17TH ANNUAL RELIABILITY ENGINEERING AND MANAGEMENT INSTITUTE

Dates: November 12-16, 1979
Place: The University of Arizona
Objective: The following subjects will be covered: reliability engineering theory and practice, mechanical reliability prediction, reliability testing and demonstration, maintainability engineering, product liability, and reliability and maintainability management.

Contact: Dr. Dimitri Kececioglu, Aerospace and Mechanical Engineering Department, Aeronautical Engineering Building No. 16, University of Arizona, Tucson, AZ 85721 - (602) 626-2495/626-3901/626-3054.

DECEMBER

MACHINERY VIBRATION ANALYSIS

Dates: December 11-13, 1979
Place: New Orleans, Louisiana
Objective: The topics to be covered during this course are: fundamentals of vibration; transducer concepts; machine protection systems; analyzing vibration to predict failures; balancing; alignment; case histories; improving your analysis capability; managing vibration data by computer; and dynamic analysis.

Contact: Spectral Dynamics Corp. of San Diego, P.O. Box 671, San Diego, CA 92112 - (714) 268-7100.

JANUARY

PROBABILISTIC AND STATISTICAL METHODS IN MECHANICAL AND STRUCTURAL DESIGN

Dates: January 7-11, 1980
Place: Tucson, Arizona
Objective: To provide practical information on engineering applications of probabilistic and statistical methods, and design under random vibration environments. Modern methods of structural and mechanical reliability analysis will be presented. Special emphasis will be given to fatigue and fracture reliability.

Contact: Dr. Paul H. Wirsching, College of Engineering, The University of Arizona, Tucson, AZ 85721 - (602) 626-3159/626-3054.

FINITE ELEMENT ANALYSIS

Dates: January 7-11, 1980
Place: Tucson, Arizona
Objective: The purpose of this course is to provide structural engineering practitioners with an understanding of the fundamental principles of finite element analysis, to describe applications of the method, and to present guidelines for the proper use of the method and interpretation of the results obtained through it. Emphasis will be placed upon the linear analysis of frameworks, plates, shells and solids; and dynamic analysis will also be treated.

Contact: Dr. Hussein Kamel, College of Engineering, The University of Arizona, Tucson, AZ 85721 - (602) 626-1650/626-3054.

ADVANCE PROGRAM

50TH SHOCK AND VIBRATION SYMPOSIUM

October 16-18, 1979

Colorado Springs, Colorado

United States Air Force
will be your host for this Symposium

THE SHOCK AND VIBRATION
INFORMATION CENTER

GENERAL INFORMATION

CONFERENCE LOCATION: Registration, Information, and Unclassified Technical Sessions are at the Antlers Plaza Hotel, Colorado Springs, CO. A classified session will be held at the U.S. Air Force Academy, Colorado Springs, CO.

REGISTRATION: All registrants must complete the UNCLASSIFIED Registration Card enclosed with this program before they may attend the technical sessions at the Antlers Plaza Hotel. In addition all registrants qualified to attend the CLASSIFIED SESSION must submit a properly completed copy of the enclosed security form. ADVANCE REGISTRATION BY MAIL IS STRONGLY RECOMMENDED. ADVANCE SECURITY CLEARANCE IS ESSENTIAL for attendance at the CLASSIFIED SESSION. Simply complete and return the appropriate form(s) to the address given thereon.

Fee: Registration fee covers the cost of the proceedings of the 50th Shock and Vibration Symposium. There is no fee for SVIC Annual Subscribers and for participants. Since the registration fee covers only the cost of the proceedings, there will be no reduced fee for part time attendance. The schedule of fees is as follows:

Subscriber Registration (for employees of
SVIC Annual Subscribers). . . . . No Fee
Participant Registration (Authors,
Speakers, Chairman, Cochairman). . . . . . . No Fee
General Registration (All Others)
(Payable to Disbursing Officer, NRL $100.00

On-Site Registration: Pre-Registrants may obtain their badges or last minute unclassified registration may be accomplished at the following times:

Antlers Plaza
Monday, October 15 . . . . 7:00 - 9:00 PM
Tuesday, October 16 . . . . . . .8:00 AM - 4:00 PM
Wednesday, October 17 . . . . .8:00 AM - 4:00 PM
Thursday, October 18 . . . . . .8:00 AM - 2:00 PM

INFORMATION: An information and message center will be located in the registration area. The phone number in the registration area is 303-473-5600. Ask for the Shock and Vibration Symposium. Telephone messages and special notices will be posted near the registration desk. All participants should check regularly for messages or timely announcements. Participants will not be paged in the sessions.

CLASSIFIED SESSION: Attendance at this session is contingent upon the establishment of a valid security clearance and Need-To-Know. A badge of special color will be given to registrants qualified to attend this session. A special re-registration will be required at the Air Force Academy just prior to the session. Photo ID is required. No cameras will be permitted and no note taking during the presentation of classified papers is allowed. Because of the special mix of papers, only appropriately cleared U.S. Citizens will be permitted to attend this session.

OUTSIDE ACTIVITIES: Once again a special planned program of outside activities is available to the one you may bring along. Take home the enclosed description of these interesting activities and, if participation is planned, have the registration form completed and return it with your Unclassified Registration form by 28 September 1979. Activities are subject to cancellation if sufficient advance registrations are not received.

SPECIAL TOUR: A tour of the DoT Transportation Test Center, Pueblo, Colorado is planned. We will leave the Antlers Plaza Hotel at 8:00 AM and we will return at approximately 2:00 PM. A description of the tour will be included in the final program and an overview of the center will be presented during the keynote session on Tuesday morning October 16. Those who wish to go on the tour may sign up at the meeting.

LODGING: A block of rooms has been reserved at the Antlers Plaza Hotel for those attending the Symposium. All reservations may be made by forwarding the enclosed Hotel Reservation Card directly to the Antlers Plaza Hotel. It is recommended that hotel reservations be made well in advance of the meeting and, in no case later than 1 October 1979.

COMMITTEE MEETING: Space is available to schedule meetings for special committees and working groups at the Symposium. To reserve space

contact SVIC. A schedule of special meetings will be printed in the final program. At present the following meetings are scheduled:

ANSI Committee S-2 and TAG for ISO-TC 108 - Thursday, October 18, 1:00 -3:00 PM

AIAA Structural Dynamics Test Committee - Thursday, October 18, 2:00 - 6:00 PM

SVIC STAFF:

Mr. Henry. C. Pusey, Director
Mr. Rudolph H. Volin
Dr. J. Gordan Showalter
Mrs. Barbara Szymanski (Secretary)
Mrs. Carol Healey (Secretary)

Shock and Vibration Information Center
Naval Research Laboratory, Code 8404
Washington, D.C. 20375

Telephone: 202-767-2220
Autovon: 297-2220

PUBLICATIONS

PROCEEDINGS: THE SUMMARIES OF PRESENTED PAPERS will be published in advance. These summaries are longer than the usual abstract and contain enough detail to evaluate their usefulness to you as an individual. By receiving these in advance, you may more effectively choose the papers you wish to hear. IN ORDER TO RECEIVE THE SUMMARIES IN ADVANCE, BE SURE YOUR REGISTRATION IS IN OUR HANDS BY 28 September 1979.

SHOCK AND VIBRATION BULLETIN No. 50: Papers presented at the 50th Symposium will, at the author's request, be reviewed and published in the Bulletin after approval by two reviewers. The discussion following these papers will be edited and published with the respective papers. Registrants who have paid the registration fee or have satisfied the registration requirements will receive a copy of the Bulletin. Additional sets of the 50th Bulletin will be sent to Annual Subscribers. Others may purchase the Bulletin from the Shock and Vibration Information Center. The price is $100.00 for each set delivered in the United States.

OTHER PUBLICATIONS: Sample copies of current publications of the Shock and Vibration Information Center may be examined at the registration area. Order blanks are available for those wishing to use them.

50th SYMPOSIUM PROGRAM COMMITTEE

Mr. Jess Jones
NASA, Marshall Space Flight Center
Huntsville, AL

Dr. Kent Goering
Defense Nuclear Agency
Washington, D.C. 20305

Mr. Jerome Pearson
Air Force Flight Dynamics Laboratory
Wright-Patterson AFB, OH

Mr. Kenneth T. Cornelius
David W. Taylor Naval R&D Center
Bethesda, MD

Dr. Grant Gerhart
US Army Tank Automotive Command
Warren, MI

KEYNOTE SESSION

(Unclassified) 9:00 A.M. **Tuesday, October 16**

Chairman: Mr. Jerome Pearson
Air Force Flight Dynamics Laboratory
Wright-Patterson AFB, OH

Cochairman: Mr. Henry C. Pusey
Shock and Vibration Information Center
Naval Research Laboratory
Washington, D.C.

Welcome: Lieutenant General Kenneth L. Tallman
Superintendent, U.S. Air Force Academy
Colorado Springs, CO

Colonel George F. Cudahy
Commander, Air Force Flight Dynamics Laboratory
Wright-Patterson AFB, OH

Invited Speakers: Lieutenant General Robert J. Baer
Deputy Commander, U.S. Army Material Development and Readiness Command
Alexandria, VA

Dr. T.G. Horwath
Director of Navy Technology
Headquarters, Naval Material Command
Washington, D.C.

Brigadier General Brien D. Ward
Director of Science and Technology
Air Force Systems Command
Andrews Air Force Base, D.C.

Mr. Wade Dorland
Transportation Test Center
Pueblo, CO

PLENARY LECTURE

2:00 P.M. **Tuesday, October 16**

MEASUREMENT

Elias Klein Memorial Lecture presented by
Dr. Robert M. Mains, Washington University, St. Louis, MO

Session 1 (Unclassified) 3:00 P.M. **Tuesday, October 16**

INSTRUMENTATION

Chairman: Dr. Peter Baade, Carrier Corporation, Syracuse, NY

Cochairman: Mrs. Phyllis Bolds, Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, OH

1. Concepts and Transducers Used in Measuring Dynamic Mass - R.R. BOUCHE, Bouche Laboratories, Sun Valley, CA
2. State-of-the-Art of Mobility Measurement Techniques - Progress Review - D.J. EWINS, Imperial College, London, England
3. A Method for Experimentally Determining Rotational Mobilities of Structures - S.S. SATTINGER, Westinghouse Electric, Bettis Atomic Power Laboratory, West Mifflin, PA
4. A Precision Inertial Angular Vibration Measuring System - R.B. PETERS, Systron-Donner Corporation, Concord, CA and P.H. MERRITT, Air Force Weapons Laboratory, Kirtland AFB, NM
5. Shock Measurement During Ballistic Impact into Armored Vehicles - W. SCOTT WALTON, U.S. Army Aberdeen Proving Ground, Aberdeen Proving Ground, MD
6. Transient Effects in Acoustic Sound Reduction Measurements - A.J. KALINOWSKI, Naval Underwater Systems Center, New London, CT

Session 2 (Unclassified) 3:00 P.M. **Tuesday, October 16**

DATA ANALYSIS

Chairman: Mr. Allan Piersol, Bolt Beranek and Newman, Inc., Canoga Park, CA

Cochairman: Mr. John Ach, Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, OH

1. 30 Years of Analysis of Vibration and Shock Data - A.J. FRANCKEN, Institute for Mechanical Constructions TNO, Delft, Netherlands
2. Assessment of the Common Carrier Shipping Environment - F.E. OSTREM, GARD Inc/GATX, Niles, IL
3. Shock Induced in Missiles During Truck Transport - D.B. MEEKER and J.A. SEARS, Pacific Missile Test Center, Point Mugu, CA
4. Statistical Estimation of Simulated Yield and Overpressure - P. MLAKER and R.E. WALKER, USAE Waterways Experiment Station, Vicksburg, MS
5. Automatic Data Channel Calibration and Noise Identification - E.E. NESBIT, Lawrence Livermore Laboratory, Livermore, CA
6. Dynamic Characteristics of Induced Draft Fan and Its Foundation - S.P. YING and E.E. DENNISON, Gilbert/Commonwealth, Jackson, MI

PLENARY LECTURE

9:00 A.M. Wednesday, October 17

ANALYSIS AND DESIGN

Mr. Robert Hager, Boeing Company, Seattle, WA

Session 3 (Unclassified) 10:00 A.M. Wednesday, October 17

DYNAMIC ANALYSIS

Chairman: Mr. Robert Dyrdahl, Boeing Company, Seattle, WA

Cochairman: Mr. Don McCutchen, NASA - LBJ Space Center, Houston, TX

1. The Relative Complexities of Plate and Shell Vibrations - A.W. LEISSA, Ohio State University, Columbus, OH

2. Contributions to the Dynamic Analysis of Maglev Vehicles on Elevated Guideways - K. POPP, Technical Univeristy Munich, Munich, Germany

3. Techniques for Improving System Dynamic Response by Active Control - T.C. HENDERSON and R.R. STRUNCE, Jr., Charles Stark Draper Laboratory, Inc., Cambridge, MA

4. Limitations on Random Input Forces in Random Decrement Computation for Modal Identification - S.R. IBRAHIM, Old Dominion University, Norfolk, VA

5. Structural-Dynamic Characterization of a Prototype 1200 Kilovolt Electrical Transmission-Line System - S. SMITH, Synergistic Technology Inc., Cupertino, CA

6. In-Fluid Cylindrical Beam Vibration with Multi-Degree of Freedom Absorbers - B.E. SANDMAN, Naval Underwater Systems Center, Newport, RI

Session 4 (Unclassified) 10:00 A.M. Wednesday, October 17

DESIGN TECHNIQUES

Chairman: Dr. J. Paul Walsh, Consultant, Sherwood Forest, MD

Cochairman: Mr. Brian Keegan, NASA Goddard Space Flight Center, Greenbelt, MD

1. Analysis and Design of the Shuttle Remote Manipulator System Mechanical Arm for Launch Dynamics Environment - D.M. GOSSAIN, E. QUITTNER, and S.S. SACHDEV, Spar Aerospace, Toronto, Canada

2. Structural Dynamic Characteristics of the Space Shuttle Reaction Control Thrusters - G.L. SCHACHNE and J.H. SCHMIDT, The Marquardt Company, Van Nuys, CA

3. Evaluation of Airborne Laser Beam Jitter Using Structural Dynamics Computer Codes and Control System Simulations - C.L. BUDDE and P.H. MERRITT, Air Force Weapons Laboratory, Kirtland AFB, NM and C.D. JOHNSON, Anamet Laboratories, Inc., San Carlos, CA

4. Preliminary Hardness Evaluation Procedure for Identifying Shock Isolation Requirements - R.J. BRADSHAW, Jr., U.S. Army Engineer Division, Huntsville, AL and P.N. SONNENBURG, U.S. Army Construction Engineering Research Laboratory, Champaign, IL

5. Generalized Graphical Solution for Estimating Recoilless Rifle Breech Blast Overpressures and Impulses - P.S. WESTINE, G. FRIESENHAHN, and J. REIGEL, Southwest Research Institute, San Antonio, TX

6. Dynamic Stability of Fibrous Composite Cylinders Under Pulse Loading - S. DHARMARAJAN, San Diego State Univeristy, San Diego, CA

PLENARY LECTURE

2:00 P.M. Wednesday, October 17

MATERIALS IN DYNAMICS

Mr. Richard Shea and Dr. John Mescall

U.S. Army Materials & Mechanics Research Center

Watertown, MA

Session 5 (Unclassified) 3:00 P.M. Wednesday, October 17

DYNAMIC PROPERTIES OF MATERIALS

Chairman: Dr. David I.G. Jones, Air Force Materials Laboratory, Wright-Patterson AFB, OH

Cochairman: Mr. Ahid Nashif, Anatrol Corporation, Cincinnati, OH

1. Material Damping as a Means of Quantifying Fatigue Damage in Composites- P.J. TORVIK and C.A. BOURNE, Air Force Institute of Technology, Wright-Patterson AFB, OH

2. Modeling a Temperature Sensitive Confined Cushioning System - V.P. KOBLER, U.S. Army Missile Command, Huntsville, AL, R.M. WYSKIDA and J.D. JOHANNES, University of Alabama in Huntsville, Huntsville, AL

3. Vibration of a Cracked Rectangular Plate - M.S. EWING, United States Air Force Academy, CO

4. Lateral Instabilities During Spin Tests of a Pendulously Supported Disc - F.H. WOLFF, A.J. MOLNAR, G.O. SANKEY, and J.H. BITZER, Westinghouse Research and Development Center, Pittsburgh, PA

5. Sonic Fatigue Testing of the NASA L-1011 Composite Aileron - J. SOOVERE, Lockheed California Company, Burbank, CA

6. Fatigue Life Prediction for Multi-Level Step-Stress Applications - R.G. LAMBERT, General Electric Company, Utica, NY

Session 6 (Unclassified) 3:00 P.M. Wednesday, October 17

APPLICATIONS OF MATERIALS

Chairman: Dr. Jack Henderson, Air Force Materials Laboratory, Wright-Patterson AFB, OH

Cochairman: Dr. Lynn Rogers, Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, OH

1. Invited Paper - J.L. GOLDBERG, CSIRO National Measurement Laboratory, Lindfield, N.S.W. Australia

2. An Application of Tuned Mass Dampers to the Suppression of Severe Vibration in the Root of an Aircraft Engine Test Cell - J.L. GOLDBERG, N.H. CLARK, and B.H. MELDRUM, CSIRO National Measurement Laboratory, Lindfield, N.S.W. Australia

3. Comparison of Analytical and Experimental Results for a Semi-Active Vibration Isolator - E.J. KRASNICKI, Lord Corporation, Erie, PA

4. An Experimental Investigation of Noise Attenuating Techniques for Space Shuttle Canisters - L. MIRANDY, General Electric, Philadelphia, PA, and J. SCOTT and F. ON, NASA Goddard Space Flight Center, Greenbelt, MD

5. A New Method of Improving Spectra Shaping in Reverberant Acoustic Chambers - J.N. SCOTT, NASA Goddard Space Flight Center, Greenbelt, MD and R.L. BURKHARDT, Northrop Services, Greenbelt, MD

6. Design Integrity Methods Including Damping for Electronic Packages - J.M. MEDAGLIA, General Electric Space Division, Philadelphia, PA

PLENARY LECTURE

9:00 A.M. Thursday, October 18

DYNAMIC TESTS
Dr. Allen Curtis
Hughes Aircraft Company, Culver City, CA

Session 7 (Unclassified) 10:00 A.M. Thursday, October 18

VIBRATION AND ACOUSTICS I

Chairman: Mr. Charles E. Thomas, Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, OH

Cochairman: Mr. Ralph Bingman, Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, OH

1. Unique Solutions to Shock and Vibration Problems for Electronics Equipment - W.J. VITALIANO, Harris Corporation, Melbourne, FL

2. A Method to Determine Realistic Random Vibration Test Levels Taking into Account Mechanical Impedance Data - O. SYLWAN, IFM Akustikbyran AB, Stockholm, Sweden

3. A Method to Determine Realistic Random Vibration Test Levels Taking into Account Mechanical Impedance Data, Part II: Verification Tests - T. HELL, SAAB-SCANIA AB, LINKOPING Sweden

4. Vibration Analysis of a Helicopter Plus an Externally-Attached Carrier Structure - D.J. EWINS, J.M.M. SILVA and G. MALECI, Imperial College, London, England

5. Improving Vibration Techniques for Detecting Workmanship Defects in Electronic Equipment - J.W. BURT and M.A. CONDOURIS, U.S. Army Electronics Research & Development Command, Ft. Monmouth, NJ

6. The Application of Transient Waveform Control to Environmental Mission Profile Testing - E. DEJONG, Pacific Missile Test Center, Point Mugu, CA

Session 8 (Unclassified) 10:00 A.M. Thursday, October 18

SHOCK TESTING

Chairman: Mr. Max McWhirter, Albuquerque, NM

Cochairman: Mr. I.B. Irving, Johns Hopkins University, Applied Physics Laboratory, Laurel, MD

1. Earthquake Engineering in the People's Republic of China - P.C. JENNINGS, California Institute of Technology, Pasadena, CA

2. An Overview of Shock Analysis and Testing in the Federal Republic of Germany - K.E. MEIER-DORNBERG, Technische Hochschule, Darmstadt, Federal Rep. of Germany

3. Measurement of Dynamic Structural Characteristics of Massive Buildings by High Level Multipulse Techniques - D.G. YATES and F.B. SAFFORD, Agbabian Associates, El Segundo, CA

4. An Optimal Procedure for Testing the Operability of Equipment Under Seismic Disturbances - C.W. de SILVA, Carnegie-Mellon University, Pittsburgh, PA & F. LOCEFF and K.M. VASHI, Westinghouse Electric Corporation, Pittsburgh, PA

5. Conservatism in Shock Analysis and Testing - T.L. PAEZ, The University of New Mexico, Albuquerque, NM

6. Response and Failure of Underground Reinforced Concrete Plates Subjected to Blast - C.A. ROSS, C.C. SHAUBLE, University of Florida Graduate Engineering Center, Eglin AFB, FL and P.T. NASH, U.S. Air Force Armament Laboratory, Eglin AFB, FL

Session 9 (Unclassified) 10:00 A.M. Thursday, October 18

SPECIAL TOPICS IN DYNAMICS

Chairman: Dr. George Morosow, Martin Marietta Corporation, Denver, CO

Cochairman: Mr. Charles Moening, The Aerospace Corporation, Los Angeles, CA

1. Transfer-Matrix Analysis of Dynamic Response of Composite-Material Structural Elements with Material Damping - M.M. WALLACE and C.W. BERT, University of Oklahoma, AMNE Research Center, Norman, OK

2. Dynamic Loading of Metal Riveted Joints - R.L. SIERAKOWSKI, C.A. ROSS, University of Florida Graduate Engineering Center, Eglin AFB, FL and W.S. STRICKLAND, U.S. Air Force Armament Laboratory, Eglin AFB, FL

3. Whipping Analysis Techniques for Ships and Submarines - K.A. BANNISTER, Naval Surface Weapons Center, Silver Spring, MD

4. Dynamics of Long Vertical Cables - F.H. WOLFF, Westinghouse R&D Center, Pittsburgh, PA

5. Drop Weight Ground Shock Simulation Development - C.R. WELCH and S.A. KIGER, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS

6. The Vibration Test Unit - A Unique Rail Vehicle Vibration Test Facility - A. NINTZEL and R. COUPLAND, Wyle Laboratories, Colorado Springs, CO

   The Application of Computers to Dynamic Rail Vehicle Testing - J. STITH and B. CLARK, Wyle Laboratories, Colorado Springs, CO

Session 10A (Unclassified) 2:00 P.M. Thursday, October 18

VIBRATION AND ACOUSTICS II

Chairman: Mr. Joseph Gaudet, Sanders Associates, Manchester, NH

Cochairman: Mr. Tommie Dobson, 6585th Test Group, Holloman AFB, NM

1. Single Point Random and Multi-Shaker Sine Spacecraft Modal Testing - M. FERRANTE, C. STAHLE and D. BRESKMAN, General Electric - Space Division, Philadelphia, PA

2. Bias Errors in a Random Vibration Extremal Control Strategy - D.O. SMALLWOOD and D.L. GREGORY, Sandia Laboratories, Albuquerque, NM

3. Low Frequency Structural Dynamics of the Space Shuttle Solid Rocket Booster Motor During Static Tests - M.A. BEHRING and D.R. MASON, Thiokol Corporation/Wasatch Division, Brigham City, UT

4. Elimination of a Discrete Frequency Acoustical Buzz Phenomenon Associated with the Space Shuttle Main Engine Oxidizer Valve/Duct System - L.A. SCHUTZENHOFER, J.H. JONES, R.E. JEWELL and R.S. RYAN, NASA Marshall Space Flight Center, AL

Session 10B (Unclassified) 3:40 P.M. Thursday, October 18

FRAGMENTS

Chairman: Dr. Marcel L. Salive, David Taylor Naval Ship R&D Center, Bethesda, MD

Cochairman: Mr. Richard Chalmers, Naval Ocean Systems Center, San Diego, CA

1. Scaling of Initiation of Explosives by Fragment Impact - W.E. BAKER and M.G. WHITNEY, Southwest Research Institute, San Antonio, TX

2. Equations for Determining Fragment Penetration and Perforation Against Metals - I.M. GYLLENSPETZ, National Defence Research Institute (FOA), Stockholm, Sweden (currently studying with Southwest Research Institute, San Antonio, TX)

3. Prediction of Fragment and Blast Hazards Around Submarines - J.J. KULESZ, P.K. MOSELEY and M.G. WHITNEY, Southwest Research Institute, San Antonio, TX

4. Breaching of Structural Steel Plates Using Explosive Disks - D.L. SHIREY, Sandia Laboratories, Albuquerque, NM

Session 11 (Unclassified) 2:00 P.M. Thursday, October 18

SHORT DISCUSSION TOPICS

Chairman: Mr. Kenneth Cornelius, David W. Taylor Naval Ship Research and Development Command, Bethesda, MD

Cochairman: Dr. Grant Gerhart, Army Tank Automotive Research and Development Command, Warren, MI

This session will program papers covering progress reports on current research efforts and unique ideas, hints and kinks on instrumentation, fixtures, testing, analytical short cuts and so forth. It is intended to provide a means for up-to-the-minute coverage of research programs and a forum for the discussion of useful ideas and techniques considered too short for a full-blown paper.

Complete titles of short talks will be published in the final program.

Thursday, October 18

A tour of the DoT Transportation Test Center, Pueblo, Colorado is planned. We will leave the Antler Plaza Hotel at 8:00 AM and we will reutrn at approximately 2:00 PM.

A description of the tour will be included in the final program and an overview of the center will be presented during the keynote session on Tuesday morning October 16. Those who wish to go on the tour may sign up at the meeting.

ABSTRACTS FROM THE CURRENT LITERATURE

Copies of articles abstracted in the DIGEST are not available from the SVIC or the Vibration Institute (except those generated by either organization). Inquiries should be directed to library resources. Government reports can be obtained from the National Technical Information Service, Springfield, VA 22151, by citing the AD-, PB-, or N- number. Doctoral dissertations are available from University Microfilms (UM), 313 N. Fir St., Ann Arbor, MI; U.S. Patents from the Commissioner of Patents, Washington, D.C. 20231. Addresses following the authors' names in the citation refer only to the first author. The list of periodicals scanned by this journal is printed in issues 1, 6, and 12.

ABSTRACT CONTENTS

ANALYSIS AND DESIGN

ANALYTICAL METHODS

(Also see Nos. 1587, 1588, 1589)

79-1488

Asymptotic Dynamical Equations for an Ensemble of Nonlinear Dispersive Waves

T. Kawahara and A. Jeffrey
Dept. of Engrg. Math., The Univ., Newcastle-upon-Tyne, UK, Wave Motion, 2 (1), pp 83-94 (Apr 1979) 31 refs

Key Words: Wave propagation, Perturbation theory

Self-consistent dynamical equations are derived for the propagation and interaction of an ensemble of short waves and a long wave propagating in a nonlinear dispersive medium. The method of multiple scales is applied to simple model systems to develop systematically an asymptotic perturbation analysis and to clarify the structure of the approximations that are involved. Some properties of these interaction equations are examined, taking into account their relationship to other existing equations for single or several waves.

79-1489

On the Evolution Law of Weak Discontinuities for Hyperbolic Quasi-Linear Systems

G. Boillat and T. Ruggeri
Universite de Clermont, Departement de mathematiques, Clermont-Ferrand, France, Wave Motion, 2 (1), pp 149-152 (Apr 1979) 10 refs

Key Words: Wave propagation

It is shown that the law of propagation of weak discontinuities obtained by A. Jeffrey is in agreement with the Bernoulli's law found by other authors.

79-1490

An Iteration Procedure and Bounds for the Eigenvalues for a Class of Non-Selfadjoint Eigenvalue Problems

M. Bredehoft and W. Hauger
Fachbereich Elektrotechnik, HSBw Hamburg, Hamburg, West Germany, Mech. Res. Comm., 6 (2), pp 105-111 (1979) 7 refs

Key Words: Eigenvalue problems, Boundary value problems

The concepts of self-adjointness and of Rayleigh's quotient, generalized by Leipholz to a class of non-selfadjoint eigenvalue problems, are considered. In these investigations, various numerical examples are presented which demonstrate that the generalized Rayleigh quotient leads to satisfactory results with only very little numerical effort.

79-1491

Effective Mass, an Important Concept for the Dynamic Characterization of Structures in Case of Base Excitation. Theory and Applications (La Masse Effective, Un Concept Important Pour la Caracterisation Dynamique des Structures Avec Excitation de la Base - Theorie et Applications)

J. Imbert and A. Mamode
Centre National d'Etudes Spatiales, Toulouse, France, Rept. No. CNES-NT-83, 41 pp (Aug 1978)
(In French)
N79-16313

Key Words: Dynamic structural analysis, Dynamic properties, Foundations, Spacecraft

A method based on the effective mass concept, for the dynamic characterization of structures in case of base excitation is described. A complete theoretical formulation including effective mass properties and modal truncation effects is presented. Typical applications which illustrate the practical advantages of this method for solving dynamic problems of space vehicles are given.

79-1492

The Solution of Structural Dynamics Problems by the Generalized Euler Method

A.G. Collings and G.J. Tee
The Univ. of Auckland, New Zealand, Computers Struc., 10 (3), pp 505-515 (June 1979) 4 figs, 18 refs

Key Words: Dynamic structural analysis, Computer-aided techniques

Stiff systems of second-order ordinary differential equations, which describe the vibration of structures subject to dynamic loading (for example, by earthquakes) may be solved by a variety of numerical algorithms. A one-parameter generalization of Euler's classical scheme for ordinary differential equations is investigated, and is shown to be applicable to such problems.

NUMERICAL ANALYSIS

79-1493

On the Use of Banded-Matrices in Dynamic Analysis

A.B. Agrawal, A.A. Mufti, and L.G. Jaeger

M.N.R. Engrg. College, Allahabad, U.P., India, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 425-432, 4 figs, 2 tables, 20 refs

Key Words: Dynamic structural analysis, Matrix methods, Seismic excitation

The problems involving the nonlinearity of the constitutive materials in structural engineering are often solved numerically using the finite element method. The numerical analysis techniques are usually based on 'incremental variable elasticity' procedure, and require the solution of the force-displacement relationships of the form [K] (δ) = (P) repeatedly or several times. This paper reviews the use of the band-solver and the frontal routine in solving these equations (a set of linear equations).

OPTIMIZATION TECHNIQUES

(Also see No. 1589)

79-1494

Aspects of Optimal Design in Dynamic Systems

D.M. Titterington

Dept. of Statistics, Princeton Univ., NJ, Rept. No. TR-141-SER-2, 35 pp (Sept 1978)

AD-A062 750/5GA

Key Words: Optimum design, Parameter identification technique, Dynamic systems

This paper attempts to provide an introduction for statisticians to the version of optimal experimental design theory for parameter estimation in regression models that is appropriate to dynamic systems. The paper consists of three main parts: first, a glossary of some terminology in control engineering and an introduction to the main aspects of dynamic systems; second, a summary of the principal results and patterns in optimal experimental design theory; and third, the ways in which the latter carry over to dynamic models. These applications are split roughly into those in which sampling items are selected.

STATISTICAL METHODS

(Also see No. 1543)

79-1495

Dynamical Systems with a Large Number of Degrees of Freedom: A Stochastic Mathematical Analysis for a Class of Deterministic Problems

N. Bellomo and G. Pistone

Istituto di Meccanica Razionale, Istituto Matematico Politecnico, Torino, Italy, Mech. Res. Comm., 6 (2), pp 75-80 (1979) 11 refs

Key Words: Multidegree of freedom systems, Stochastic processes, Mathematical models

This paper deals with the analysis of some mathematical methods for the study of a class of abstract dynamical systems constituted by a large number of objects, as they can be found in classical mechanics as well as in statistical mechanics, in the theory of systems, or, more in general, in the mathematical modeling of large systems.

FINITE ELEMENT MODELING

79-1496

An Evaluation of Incompatible Displacement Modes in Finite Element Dynamic Analysis

A.R. Chandrasekaran

Dept. of Earthquake Engrg., Univ. of Roorkee, U.P., India, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 419-424, 1 fig, 4 tables, 4 refs

Key Words: Finite element technique

In finite element dynamic analysis, as compared to static analysis, an attempt is always made to reduce the number

of degrees of freedom. One of the methods involves the use of incompatible displacement modes. Using this technique, the accuracy of the finite elements is supposed to be improved even with coarser mesh. An evaluation of such elements for two dimensional analysis of a dam cross-section has been made in this paper.

PARAMETER IDENTIFICATION

79-1497

Identification of Unsteady Effects in Lift Buildup

P. Mereau, R. Hirsch, G. Coulon, and A. Rault

Adjutant General Center, Washington, D.C., In: AGARD Dyn. Stability Parameters, Nov 1978, 14 pp (for primary document see N79-15061)

N79-15033

Key Words: Aerodynamic loads, Parameter identification technique, Transient excitation

A methodology to identify unsteady aerodynamic forces from flight test data is proposed and developed in the case of uncoupled longitudinal motion. This method includes several steps based upon linearity and frequency separation: data filtering, classical stability and control parameters identification, transient forces estimation, and unsteady terms identification.

SURVEYS AND BIBLIOGRAPHIES

79-1498

Nonlinear Acoustics (A Bibliography with Abstracts)

B. Carrigan

National Technical Information Service, Springfield, VA, 143 pp (Mar 1979)

NTIS/PS-79/0184/6GA

Key Words: Bibliographies, Sound propagation

Studies include nonlinear acoustic theory and applications to sound transmission in the atmosphere, underwater, solids, liquids, and gases. Nonlinear relationships are included for shock tubes, sonar equipment, sonic booms, acoustic defectors, sound generators, acoustic delay lines, porous materials, pipes, ducts, and jet engine noise. (This updated bibliography contains 134 abstracts, 13 of which are new entries to the previous edition.)

MODAL ANALYSIS AND SYNTHESIS

79-1499

On the Vibratory Response of Close-Coupled Systems

S. Mahalingam

Dept. of Mech. Engrg., Univ. of Sri Lanka, Peradeniya, Sri Lanka, J. Sound Vib., 63 (2), pp 189-200 (Mar 22, 1979) 8 figs, 8 refs

Key Words: Harmonic excitation, Forced vibration, Modal analysis

Classical theory for the vibratory response of undamped systems to harmonic excitation is extended by the formulation of cross-receptances of close-coupled systems in continued product form. Receptances for force excitation - and also transfer ratios for displacement excitation - are represented by formulae of Biot-Duncan type for straight line and branched torsional systems. Degenerate forms of the receptance diagrams and special modes of response involving partial vibration are discussed in detail.

COMPUTER PROGRAMS

GENERAL

79-1500

Development of a Moderately Sized Finite Element Program for Nonlinear Structural Analysis

W.E. Haisler

Dept. of Aerospace Engrg., Texas A&M Res. Foundation, College Station, TX, Rept. No. NASA-CR-150882; TR-3207-77-1, 182 pp (June 1977)

N79-15324

Key Words: Computer programs, Dynamic structural analysis, Finite element technique, Nonlinear theories

AGGIE 1 is a computer program for predicting the linear and nonlinear, static and dynamic structural response of two-and three-dimensional continuum solids. The program is based on isoparametric finite elements and allows for 2-D plane stress, plane strain, and axisymmetric analyses and general 3-D analyses. Large strain kinematics is based on the total Lagrangian formulation. Materially nonlinear models include several elastic-plastic work-hardening models as well as an incompressible Mooney-Rivlin model. Included in this report is a brief description of the theoretical bases

of the program, the material models used, the element library and the overall program organization. Instructions for data input preparation are given in detail. Several sample problems are given along with the required program input and program generated solutions.

relation functions are analyzed and correlation techniques are applied to the location of both narrowband and broadband sources. An experimental noise-location device used for investigating the noise emitted from an oil refinery is described which consists of a two-microphone 'telescope' and correlator. Results with narrowband and wideband sources are presented.

79-1501

Program HOLZER: Computer Program to Determine the Natural Frequencies of a Multimass Torsional Vibration System

M.J. Dawson and H.G. Denkhaus
Strength Mechanics Div., National Mechanical Engrg. Res. Inst., Pretoria, South Africa, Rept. No. CSIR-ME-1559; ISBN-0-7988-1325-3, 37 pp (Mar 1978)
N79-16299

Key Words: Computer programs, Natural frequencies, Torsional vibration

This report describes a computer program that determines the natural frequencies of a multimass torsional vibration system. A brief introduction to torsional vibrations is included.

ENVIRONMENTS

ACOUSTIC

(Also see Nos. 1498, 1601)

79-1502

The Identification of a Source of Noise and the Measurement of its Effect by a Correlation Method

D. Audoynaud, A. Hellion, and B. Escudie
Royal Aircraft Establishment, Farnborough, UK, Rept. No. RAE-Lib-Trans-1970; BR66044, 36 pp (July 1978) (Engl. transl. from Rev. d'Acoustique (France), no. 34, 1975, pp 8-20)
N79-15761

Key Words: Noise source identification, Correlation technique

The problem of identifying the position and characteristics of distant noise sources by methods based on signal analysis is considered. The properties of random functions and cor-

PERIODIC

(See No. 1499)

SEISMIC

(Also see Nos. 1523, 1599, 1647, 1649, 1680, 1681)

79-1503

Seismic Considerations for Electrical Equipments

G.C. Parakh, Nazir-Ul-Haq, and K.C. Lahiry
Switchgear Engrg. Div., Bharat Heavy Electricals, Ltd., Bhopal, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 323-328, 1 fig, 4 tables, 5 refs

Key Words: Electrical machines, Seismic excitation, Electric power plants

This paper deals with various design considerations of electrical equipments for suitability under seismic conditions. Various test procedures to evaluate the performance of these equipments have been discussed.

79-1504

Estimation of Relative Velocity Spectra

M.D. Trifunac and J.G. Anderson
Dept. of Civil Engrg., Univ. of Southern California, Los Angeles, CA 90007, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 9-14, 6 figs, 3 tables, 13 refs

Key Words: Scaling, Spectrum analysis, Single degree of freedom systems, Earthquake response

This paper summarizes a new method of empirical scaling of relative velocity spectrum amplitudes of a single-degree-of-freedom viscously damped oscillator subjected to strong earthquake ground motion. Regression models are pre-

sented for scaling of spectral amplitudes in terms of earthquake magnitude and epicentral distance, and of Modified Mercalli Intensity at a site. The effects of geologic setting of the station and the distribution of spectral amplitudes have been included.

79-1505

Lifeline Earthquake Engineering in Japan

K. Kubo, T. Katayama, and M. Ohashi
Inst. of Industrial Sci., Univ. of Tokyo, Tokyo, Japan, ASCE, Jr. Technical Councils, 105 (TC1), pp 221-238 (Apr 1979)

Key Words: Bridges, Underground pipelines, Earthquake resistant structures

General philosophies behind the current earthquake-resistant considerations for lifeline systems in Japan are reviewed. Relevant Japanese specifications are listed with some comments. Soil problems are considered in relationship to the earthquake resistance of lifeline systems, including liquefaction, embankment failures, and damage to buried pipelines. Some of the technical lessons obtained from past Japanese earthquakes are described for buried pipelines and bridges, and several aspects of the current Japanese practices to meet these problems are analyzed. Need for future research in the field of lifeline earthquake engineering is summarized.

79-1506

Approximate Analysis of Elastically Restrained Circular Slabs Subjected to Dynamic Loads

A.S. Arya and D.K. Paul
Dept. of Earthquake Engrg., Univ. of Roorkee, U.P., India, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 369-374, 7 figs, 1 table, 5 refs

Key Words: *Slabs, Panels, Circular panels, Seismic response,* Seismic design

In large circular industrial structures, the response of horizontal slabs to the vertical component of earthquake could be of considerable importance since it may significantly influence the response of facilities resting over them. The end conditions of such circular slabs may be simply supported, fixed, or elastically restrained by the supporting cylindrical shell. For design of such elastically restrained slabs for dynamic loads, an approximate analysis is developed based on static deflected shape.

79-1507

Behavior of Tunnel Liner Model on Seismic Platform

D.I. Yakovlevich and M.J. Borisovna
TsNIIS, Moscow, USSR, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 379-382, 4 figs, 6 refs

Key Words: Tunnels, Tunnel linings, Seismic response, Interaction: soil-structure, Test models, Environmental effects, Experimental data

Presented in this article are procedures and results of studies of stress and strain in a tunnel liner model when the seismic model is in the state of vibration.

79-1508

Aseismic Design of Tunnel Structures

N.N. Fotieva and N.S. Bulychev
Research Inst. of Bases and Underground Structures, Moscow, USSR, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 375-378, 2 figs, 14 refs

Key Words: Tunnels, Tunnel linings, Underground structures, Seismic design

This paper deals with the basic principles of lining design for tunnels and other long underground structures located at great depths in seismic regions.

SHOCK

(Also see Nos. 1524, 1529)

79-1509

Response Spectra for Design of Structures Subjected to Under Ground Blasts

L.S. Srivastava, V.K. Puri, S. Basu, B. Chandra, and A.S. Arya
Dept. of Earthquake Engrg., Univ. of Roorkee, U.P., India, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 27-30, 6 figs, 3 tables, 3 refs

Key Words: *Blast resistant structures,* Mines (excavations), Underground explosions

The paper deals with the problem of determination of accelerations for design of structures near blasting areas. A field study using trial blast tests using charges comparable with working blasts was conducted in a coal field, the results of which are reported.

79-1510

Ground Response Studies in Three Western U.S. Cities

A.M. Rogers and W.W. Hays

U.S. Geological Survey, Denver, CO, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 21-26, 5 figs, 1 table, 13 refs

Key Words: Blast resistant structures, Nuclear explosion effects

Ground response has been measured in the cities of Las Vegas, Long Beach, and Salt Lake City using nuclear-explosion ground motions produced at the Nevada Test Site. The principal characteristics of the diverse patterns of ground response in each city can be explained in terms of known variations in lithologic, geologic, and physical properties.

79-1511

Investigation of Underground Explosions with Model Tests. Measurements on the Platform

S. Rollvik and M. Vigstad

Norwegian Defence Research Establishment, Kjeller, Rept. No. NDRE-VM-61, 66 pp (Aug 1978)

AD-A062 801/6GA

Key Words: Underground explosions, Scaling, Model testing

Model tests in three scales were undertaken to examine if simple scaling laws can be used to investigate underground explosions. Charges were detonated in steel tubes, and pressures and arrival times were measured in the tube and on a platform. The objective of the tests is described in more detail in AD-A062 800, which also describes the results from the measurements in the tube. This report describes the results from the measurements on the platform.

79-1512

Investigation of Underground Explosions with Model Tests: Measurements in the Tube

S. Rollvik and M. Vigstad

Norwegian Defence Research Establishment, Kjeller, Rept. No. NDRE-VM-60, 88 pp (Mar 1978)

AD-A062 800/8GA

Key Words: Underground explosions, Scaling, Model testing

Model tests in three scales were undertaken to examine if simple scaling laws can be used to investigate underground explosions. Charges were detonated in steel tubes, and pressures and arrival times were measured in the tube and on a platform. This report describes the results from the measurements in the tube. A systematic deviation from the scaling laws is observed. The dependence of this deviation on tube diameter, charge weight and wall roughness is examined. The results from the measurements on the platform are given in AD A-062 801.

79-1513

Dynamic Blast Tests at Yerraguntla

S. Prakash, K. Kumar, S. Saran, and S.S. Saini

Univ. of Roorkee, U.P., India, Symp. Earthquake Engrg., Univ. of Roorkee, Roorkee, India, Oct 5-7, 1978, pp 137-144, 8 figs, 3 tables, 10 refs

Key Words: Industrial facilities, Blast response, Seismic response, Experimental data

In this study, blasts of charge 25 kg, 50 kg, 75 kg and 100 kg were made at a quarry site at different locations. Records of acceleration were taken using acceleration pick ups at various distances from the center of the blast. Results have been interpreted in the form of suitable design charts.

GENERAL WEAPON

79-1514

Predicting Noise Impact in the Vicinity of Small-Arms Ranges

J. McBryan

Construction Engrg. Research Lab. (Army), Champaign, IL, Rept. No. CERL-IR-N-61, 22 pp (Oct 1978)

AD-A062 718/2GA

Key Words: Weapons systems, Noise measurement, Data processing

This report describes the data collection and reduction methods used to determine equations to provide sound-exposure level (SEL) vs distance curves for impulsive noise at Army small-arms ranges. It also describes the method for calculating SEL per round at any distance for M14 and M16 rifles, a .45 caliber pistol, and a M60 machine gun, and the tabular procedure for predicting the day/night average sound level (Ldn) at Army small-arms ranges. This in turn allows for prediction of noise impacts on or adjacent to Army installations.

PHENOMENOLOGY

DAMPING

79-1515

An Analysis of the Flow of a Viscoelastic Fluid Between Arbitrary Two-Dimensional Surfaces Subject to Normal High Frequency Oscillations

J.A. Tichy and M.E. Skinkle

Aeronautical Engrg. & Mechanics, Rensselaer Polytechnic Inst., Troy, NY, J. Lubric. Tech., Trans. ASME, 101 (2), pp 145-153 (Apr 1979) 13 figs, 12 refs

Key Words: Bearings, Lubrication, Viscoelastic damping

An analytic solution is presented for the flow of a viscoelastic fluid between arbitrary but sufficiently smooth two-dimensional surfaces, one of which is subjected to small high frequency oscillations normal to the other. The results are presented in terms of the complex viscosity parameters of linear viscoelasticity, and are valid for any simple viscoelastic fluid, provided the oscillation amplitude is sufficiently small. Fluid inertia effects are included although convective inertia terms are shown to be negligible through order-of-magnitude considerations.

79-1516

The Lanchester Damper - A Design Procedure for Optimizing the Damping Ratio for a Cylindrical Slug Damper Fitted to a Machine Element

Y.H.J. Au, K.W. Ng, and R.W. New

Dept. of Production Tech., Brunel Univ., Uxbridge, Middlesex, UK, J. Mech. Des., Trans. ASME, 101 (2), pp 291-297 (Apr 1979) 6 figs, 5 refs

Key Words: Self-excited vibrations, Viscous damping

The present work shows how the equations of motion for a Lanchester damper can be modified to include the effects of a damper slug rolling inside a cavity within the parent body, and of the kinetic energy of the damping fluid. The effect of the slug rolling is to reduce the performance of the damper below that predicted by the standard theory and to require a different value for damping at the optimum condition. These effects are significant when the build-up of self-excited type of vibrations are to be prevented, and when small forced vibrations are to be controlled.

79-1517

Oscillatory Damped Linear Systems

P.C. Muller

Lehrstuhl B f. Mechanik, Technische Universität München, Arcisstr. 21, D-8000 München 2, Germany, Mech. Res. Comm., 6 (2), pp 81-85 (1979) 4 refs

Key Words: Boundary value problems, Damped structures

Recently, lower bounds on the real and imaginary parts of the eigenvalues of a damped linear system in free vibration were obtained. Also a condition for subcritical damping in all modes was presented. Unfortunately his proof is only valid if the commutativity of certain matrices is satisfied. In contrast to this, here not only the proof is improved but also better results on eigenvalue bounds and on subcritical damping in all modes were obtained.

ELASTIC

79-1518

On Matched Asymptotic Expansions for Two Dimensional Elastodynamic Diffraction by Cracks

A.K. Gautesen

Dept. of Mathematics, Southern Methodist Univ., Dallas, TX 75275, Wave Motion, 2 (1), pp 127-140 (Apr 1979) 4 figs, 13 refs

Key Words: Elastic media, Cracked media, Wave diffraction

For two-dimensional diffraction by a crack in an elastic solid it is shown that the geometrical theory of diffraction represents an asymptotic solution to the equations of linear elastodynamics, which satisfies the boundary conditions of vanishing tractions on the crack faces. The analysis consists

of matching an outer solution valid far from the edge of the crack to an inner solution valid near the crack edge. Uniform corrections to the theory are given which provide a smooth transition across these boundaries.

FLUID

(Also see Nos. 1627, 1638)

79-1519

Oil Whirl Resonance

D.E. Bently and R.F. Bosmans

Mechanical Engrg. Services, Bently Nevada Corp., Minden, NV, "Fundamentals of the Design of Fluid Film Bearings" presented at the Design Engrg. Conf., Chicago, IL, May 7-10, 1979, sponsored by the Lubrication Div. of ASME, pp 131-193, 6 figs, 38 graphs, 12 refs

Key Words: Fluid-induced excitation, Oil whirl phenomena, Bearings

An experimental study of the oil whirl mechanism has resulted in the development of a technique that may be used, under certain conditions, to predict the dynamic performance of a rotating machine. This study simultaneously raised questions concerning the calculation of stability criteria for both oil whirl and oil whip. The oil whirl mechanism was investigated by observing the performance of a transparent cylindrical sleeve bearing and a steady-state unidirectional preload, plus an input forward circular perturbation force at rates that ranged from approximately 10% to 90% of rotative speed. The equations that were developed during the study of the full lubrication (360 deg) bearing, plus associated data, are presented to help clarify views on the oil whirl mechanism. Applicable reference material on bearings that has been published in the past 100 years was considered, especially the work of J.A. Cole on transparent bearings in 1957, and the perturbation studies conducted that same year by E.H. Hull.

79-1520

Time-Variant Aerodynamics of Oscillating Airfoil Surfaces in a Supersonic Flowfield

S. Fleeter and R.E. Riffel

Detroit Diesel Allison, Div. of General Motors, Indianapolis, IN, AIAA J., 17 (5), pp 465-470 (May 1979) 17 figs, 8 refs

Key Words: Airfoils, Harmonic response, Supersonic vibrations, Fluid-induced excitation

The results of an experimental study of the time-variant aerodynamics associated with harmonically oscillating single airfoil surfaces in a supersonic flowfield are presented. Six single airfoil configurations were investigated: a flat plate, wedge, flat plate-convex corner, wedge-convex corner, MCA suction surface, and MCA pressure surface.

SOIL

(Also see Nos. 1534, 1544, 1661)

79-1521

Damping in Soils: Theoretical Investigation

E.A. Palaniappan

Raba & Assoc., San Antonio, TX, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 119-124, 2 figs, 1 table, 7 refs

Key Words: Soils, Viscous damping, Coulomb friction, Hysteretic damping, Mathematical models

The mathematical models and reported experimental data regarding the nature of damping in soils have been reviewed. These models include viscous damping, Coulomb damping, and hysteretic damping. For hysteretic damping, certain concepts regarding the critical damping coefficient and damping ratio have been proposed by the author. Jacobsen's expression (1960) to determine damping ratios of materials from hysteresis loop plots has been reviewed.

79-1522

The Effects of Specimen Reconstitution on Cyclic Triaxial Test Results

W.F. Marcuson, III and F.C. Townsend

Soils and Pavements Lab Waterways Experiment Station, Vicksburg, MS, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 113-118, 8 figs, 1 table, 5 refs

Key Words: Soils, Compressive strength, Dynamic tests, Experimental data

The U.S. Army Engineer Waterways Experiment Station (WES), in connection with a dynamic analysis of Fort Peck Dam, conducted a series of dynamic laboratory tests on reconstituted specimens of Fort Peck materials to evaluate

their liquefaction potential. From a comparison of these laboratory results with other laboratory results obtained for undisturbed hydraulic-fill material, it was apparent that reconstitution did affect the results. After reviewing the present state of the art, WES conducted cyclic triaxial compression tests on tapped undisturbed specimens from Fort Peck Dam. These specimens were then reconstituted to the as-tested density, and the cyclic triaxial tests were repeated.

79-1523

Seismic Ground Response Analysis Methods Evaluation

W.W.H. Chen

Res. and Engrg. Application Div., Bechtel National Inc., P.O. Box 3965, San Francisco, CA, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 21-26, 3 figs, 12 refs

Key Words: Soils, Ground motion, Seismic response, Equivalent linearization method, Method of characteristics, Finite element technique

An evaluation of the methods available to determine the seismic ground response of horizontally layered soil deposits is presented. Four analytical approaches – the equivalent linear method, the method of characteristics, the finite element method, and the modified equivalent linear method are reviewed.

79-1524

Blast Pressure and Related Dynamic Studies on Sand Due to Foam Propellent

K.B. Agrawal and B.S. Ram

Dept. of Civil Engrg., Univ. of Roorkee, U.P., India, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 101-106, 3 figs, 1 table, 7 refs

Key Words: Sand, Soils, Explosion effects

Surficial compaction of sands results due to application of propellent. Three methods of the prediction of blast pressure characteristics due to detonation of a strip of foam propellent have been developed. Two of these methods are purely theoretical, while the third is based on field compaction test results. In the third method, named as DLS method, the dynamic settlement behavior of the sand due to detonation of propellent has been observed experimentally and the blast pressure has been computed by working back from the resulting dynamic settlement.

79-1525

Properties of Clays under Cyclic Loading

R.D. Singh, J.H. Kim, and S.R. Caldwell

Woodward-Clyde Consultants, 5120 Butler Pike, Plymouth Meeting, PA, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 107-112, 8 figs, 10 refs

Key Words: Clays, Soils, Dynamic tests, Shear strength, Experimental data, Earthquake response

This paper presents the results of a cyclic shear testing program conducted on Normal Marine and Glacial Marine clays from the Gulf of Alaska region. Soil parameters appropriate for non-linear response analyses were developed incorporating a change of properties during cyclic loading. A model based on the Normalized Soil Parameters (NSP) method of characterization is proposed for the post cyclic stress strain behavior of clays and its validity evaluated for the clays tested.

79-1526

Strain Rate Effects Under Static and Dynamic Loading of a Remolded Clay

R.P. Khera and F.N. Screwvala

Dept. of Civil and Environmental Engrg., New Jersey Inst. of Tech., Newark, NJ, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 145-150, 6 figs, 2 tables, 12 refs

Key Words: Compressive strength, Clays, Soils, Dynamic tests

Slow and fast strain rate tests were performed on a remolded illitic clay. Slow strain rate tests were the conventional consolidated undrained triaxial compression tests, whereas for the rapid strain rate tests, use of ballastic pendulum was made.

79-1527

Effect of Soil Interaction on Response of Complex Structures

S.P. Gupta and M.K. Gupta

Dept. of Earthquake Engrg. Univ. of Roorkee, U.P., India, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 295-300, 4 figs, 5 tables, 6 refs

Key Words: Interaction: soil-structure, Complex structures

The deformation caused in the subsoil and foundation changes the dynamic behavior of the Super-Structure and it is important to investigate the extent of interaction between soil and the structure. This study deals with the soil structure interaction effect on two complex structures one with large and the other with smaller base dimensions. Analysis has been carried out by considering the structures to be founded on pile foundation and in another case on raft foundation.

79-1528
Simplified Analysis for Tunnel Supports
H.H. Einstein and C.W. Schwartz
Massuchusetts Inst. of Tech., Cambridge, MA, ASCE J. Geotech. Engr. Div., 105 (GT4), pp 499-518 (Apr 1979)

Key Words: Tunnels, Supports, Interaction: soil-structure

An improved closed-form solution is developed for calculating tunnel support thrusts, moments, and displacements. The solution directly models the interaction of an elastic, circular support with an elastic, isotropic, infinite ground mass. The major improvements in this solution over other solutions in the literature are: revised formulation of the compressibility ratio; and the incorporation of the correct excavation unloading conditions for mined tunnels. The sensitivity of the tunnel support loads to variations in the relative support stiffness, support cross section, Poisson's ratio, and initial lateral stress ratio is demonstrated using the revised solution; these results are also compared to those from two other solutions in the literature. Discrepancies of up to 100% are found in the support forces calculated from the different solutions.

79-1529
Non-Linear Dynamic Analysis of Underground Structure
S.K. Thakkar
Dept. of Earthquake Engrg., Univ. of Roorkee, U.P., India, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 465-470, 4 figs, 4 refs

Key Words: Underground structures, Blast excitation, Interaction: soil-structure

The paper presents the application of visco-plastic algorithm to compute non-linear dynamic response of underground structures and the surrounding medium subjected to overground dynamic loads of a short duration. The finite-element idealization is used for spatial discretization of structures and the medium and linearized form of incremental equations of motion are employed to describe the dynamics of the system. The yielding of the surrounding medium is described by Mohr-Coulomb law. Numerical solution for a plane-strain problem of underground tunnel are obtained for a transient load.

EXPERIMENTATION

BALANCING

79-1530
Real Time Analysis in Shaft Balancing
G.F. Lang
Application Engrg., Nicolet Scientific Corp., Northvale, NJ, Diesel Gas Turbine Prog., 45 (5), pp 76-77 (May 1979) 9 figs

Key Words: Frequency analyzers, Shafts, Balancing techniques

A real time analyzer for shaft balancing is described in this article. It works successfully in reduction of unbalance-induced vibration. The time saving coastdown method of data collection has been validated and its use is encouraged.

DIAGNOSTICS

(See No. 1545)

EQUIPMENT

(Also see Nos. 1541, 1542)

79-1531
On the Test Procedures of the Derivative Balances Used in West Germany
J. VonderDecken, E. Schmidt, and B. Schulze
Dornier-System G.m.b.H., Friedrichshafen, West

Germany, In: AGARD Dyn. Stability Parameters, Nov 1978, 17 pp (for primary document see N79-15061)
N79-15067

Key Words: Test equipment, Aircraft, Spacecraft, Flight vehicles

The low-speed wind tunnels in West-Germany are equipped with three different test installations to measure dynamic stability derivatives on rigid models of aeroplanes and missiles: a mobile oscillatory apparatus with inexorable mechanical drive; a multi-degree-of-freedom forced-oscillation apparatus with electrodynamic excitation; a steady-state forced-roll apparatus with hydraulic motor drive. A short description of the measuring technique and the appropriate derivative evaluation method used with each installation is given.

FACILITIES

79-1532
Gust-Vehicle Parameter Identification by Dynamic Simulation in Wind-Tunnels
B. Krag
Institut f. Flugmechanik, Brunswick, West Germany, In: AGARD Dyn. Stability Parameters, Nov 1978, 6 pp
N79-15097

Key Words: Wind tunnels, Test facilities, Wind-induced excitation, Parameter identification technique

A description of the DFVLR (Deutsche Forschungs- und Versuchsanstalt f. Luft- und Raumfahrt) installation for dynamic simulation in wind tunnels is given. The application of this research installation in a research program and its capability and limitation are described.

79-1533
Wind Tunnel Testing of Dynamic Derivatives in West Germany
X. Hafer
Technische Universitaet, Darmstadt, West Germany, In: AGARD Dyn. Stability Parameters, Nov 1978, 12 pp
N79-15066

Key Words: Wind tunnels, Test facilities

A survey of the activities of the German national working group engaged in the development of dynamic wind tunnel test installations is given. The development of four different test rigs was planned.

79-1534
Suitability of Vibration Table Tests for Liquefaction Studies
M.K. Gupta
Dept. of Earthquake Engrg., Univ. of Roorkee, U.P., India, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 225-230, 9 figs, 8 refs

Key Words: Shakers, Foundations, Soils

Investigations were carried out on large size samples on vibration table under different types of surcharge conditions. In this paper the suitability of shake table vibration for structural foundation liquefaction studies has been discussed and it has been brought out that shake table vibration tests represent the field conditions to a better degree.

INSTRUMENTATION

79-1535
Instrumentation for Sound Power Determinations
K. Zaveri
Bruel & Kjaer, Naerum, Denmark, S/V, Sound Vib., 13 (3), pp 16-20 (Mar 1979) 9 figs, 2 tables, 6 refs

Key Words: Sound level meters

Various procedures for the measurement of sound power level are presented. Descriptions of typical instrumentation systems and recommendations for their use are included.

79-1536
A Guide to Better Understanding of Field Sound Level Calibrators
S.V. Djuric and E.R. Marteney
GenRad Inc., Bolton, MA, S/V, Sound Vib., 13 (3), pp 22-25 (Mar 1979) 3 figs

Key Words: Sound level meters, Calibrating

Field sound level calibrators for checking the acoustical and electrical performance of sound measuring instruments are described. Calibration accuracy ratings and application recommendations are included.

79-1537
Sound Level Meters - Their Use and Abuse
C. Thomsen
Bruel & Kjaer, Naerum, Denmark, S/V, Sound Vib., 13 (3), pp 28-31 (Mar 1979) 11 figs

Key Words: Sound level meters

The operating functions of sound level meters are reviewed as they affect various applications. Performance limitations of typical instruments are also discussed.

79-1538
A Computer Controlled Charge Amplifier System
H.W. Bray
Endevco, San Juan Capistrano, CA, S/V, Sound Vib., 13 (3), pp 6-10 (Mar 1979) 2 figs

Key Words: Vibration tests, Computer aided techniques

The availability of a computer controlled charge amplifier is the next logical step in automating vibration testing. Improved amplifier performance combined with the capability of digital control: brings increased efficiency in setting up a test, reduces possibility of lost data or decreased control because the amplifier gain was not selected to maximize dynamic range, and insures that the most recent gain setting of each charge amplifier has been documented.

79-1539
Design of a Fluid-Coupled Vibration Pickup
P.V. Rao
Punjab Engrg. College, Chandigarh, India, Symp. Earthquake Engrg., Oct 5-7, 1978 , Univ. of Roorkee, Roorkee, India, pp 335-338, 3 figs, 3 refs

Key Words: Vibration measurement, Measuring instruments

The paper describes design and selection of components to measure the acceleration of a reciprocating system by means of a tube filled with mercury and with a diaphragm fixed to one end of the tube. The motion of the diaphragm is measured by a capacitive sensing element. This pickup can be used for horizontal and vertical motions of the system, and for the following ranges, maximum displacement 10 mm, frequency range 1 to 200 Hz.

79-1540
Design of a Starter for Earthquake Recording
L.K. Gupta, A.R. Chandrasekaran, and L.S. Srivastava
Dept. of Earthquake Engrg., Univ. of Roorkee, U.P., India, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 5-8, 8 figs

Key Words: Measuring instrumentation, Seismometers

This paper describes the design of an electrodynamic device to act as a starter of accelerograph which records strong ground motion. The transducer for this device consists of a self generating velocity pick up. This helps prevention of starting due to spurious reasons like static tilt.

SCALING AND MODELING

(See Nos. 1504, 1511, 1512)

SIMULATORS

79-1541
Six Degrees of Freedom Large Motion System for Flight Simulators
M. Baret
Div. Simulateurs et Systemes Electroniques, Le Materiel Telephonique, Trappes, France, In: AGARD Piloted Aircraft Environ. Simulation Tech., 8 pp (Oct 1978)
N79-15995

Key Words: Flight simulation, Vibration control, Test equipment

The long-stroke, hollow-rod jack with hydrostatic bearings of the six degrees of freedom, large motion system is described. Techniques are provided that improve and reduce the level of unwanted accelerations normally generated by motion systems, while offering new possibilities in the study of control laws.

79-1542

Dynamic Characteristics of Flight Simulator Motion Systems

P.T. Kemmerling, Jr.

Aeronautical Systems Div., Wright-Patterson AFB, OH, In: AGARD Piloted Aircraft Environ. Simulation Tech., 20 pp (Oct 1978)

N79-15993

Key Words: Flight simulation, Aircraft, Dynamic properties, Test equipment

Recognition is made of the complete lack of substantive data on the quality of motion produced by multiple degree of freedom aircraft simulator motion systems, and efforts made to produce this data are discussed. Working Group No. 07 of the Flight Mechanics Panel of AGARD was given the charter to identify and define the pertinent physical characteristics of flight simulator motion systems, establish procedures for their measurement and prepare a report on their findings. The seven main characteristics identified by the Group are outlined, and efforts by several of the members to apply the characteristic techniques in laboratory measurements are discussed. Acknowledgement is made of the difficulties in establishing universally workable definitions and techniques for cataloguing motion characteristics, and alternatives are suggested.

TECHNIQUES

(Also see Nos. 1526, 1700)

79-1543

On the Application of Certain Statistical Methods to Wind-Tunnel Testing

J. McKie

Aerodynamics Dept., Royal Aircraft Establishment, Farnborough, UK, Rept. No. ARC-CP-1390; 57 pp (1978)

N79-15919

Key Words: Wind tunnel tests, Statistical analysis, Aerodynamic loads

The use of some standard statistical techniques in wind-tunnel testing is illustrated. The results of non-linear regression analysis are applied to the particular problem of comparing the data from experiments in two different tunnels on the same model. Residual variance was used as a measure of the repeatability of results and standard tests were applied to look for significant differences between the two tunnels. The accuracy of a measured aerodynamic coefficient was put in terms of confidence limits for a given proability level. A method is given for determining the minimum detectable effect of a model geometry change and also for finding the number of data points needed to measure a coefficient to a prescribed accuracy.

79-1544

Charge Explosion Sounding of Saturated Cohesionless Soils

P.L. Ivanov and N.D. Krasnikov

The Leningrad Polytechnical Inst. named after M.I. Kalinin, Leningrad, USSR, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 151-156, 8 figs, 2 tables, 5 refs

Key Words: Soils, Testing techniques, Explosives

The evaluation of density and stability of soil structure as well as possible liquefaction of saturated cohesionless soils under seismic impacts which involves sampling of soil of undisturbed structure, which present considerable difficulties, are investigated.

HOLOGRAPHY

79-1545

Stresses During Small Motions

J.D. Trolinger and R.S. Reynolds

Spectron Development Labs., Costa Mesa, CA, Industrial Res. Dev., 21 (5), pp 133-136 (May 1979) 3 figs, 5 refs

Key Words: Diagnostic techniques, Holographic techniques, Interferometers, Computer storage devices

Using the holographic interferometry technique, the authors developed procedures for the diagnostics of a recording head

of a new disc memory undergoing development. In addition to diagnostic data, these procedures have generated some very useful information for the developers of disc memories.

COMPONENTS

SHAFTS

79-1546

Constrained Balancing Techniques for Flexible Rotors

W.D. Pilkey and J.T. Bailey
Dept. of Mech. and Aerospace Engrg., Univ. of Virginia, Charlottesville, VA 22901, J. Mech. Des., Trans. ASME, 101 (2), pp 304-308 (Apr 1979) 2 figs, 3 tables, 3 refs

Key Words: Flexible rotors, Shafts, Balancing techniques

Several methods for identifying the unbalance causing deflection of a flexible rotating shaft are developed. All methods presented permit the magnitude of the balance weights to be controlled. The formulations may be grouped into categories of either time independent schemes or time dependent schemes. The formulations are also characterized by the type of measure adopted for the identification, e.g., minimax or least squares fits. Numerical results are presented for some of the methods.

79-1547

Effects of Disk Flexibility on Shaft Whirl Stability

F.J. Wilgen and A.L. Schlack, Jr.
General Mills, Inc., Minneapolis, MN 55427, J. Mech. Des., Trans. ASME, 101 (2), pp 298-303 (Apr 1979) 6 figs, 19 refs

Key Words: Shafts, Whirling

The effects of disk flexibility on the critical speeds of flexible shaft-disk systems is investigated by the method of Liapunov. The model consists of a flexible, continuous disk rigidly attached at an arbitrary location along a flexible, continuous shaft which is mounted on short, end bearings. Whirl speed stability boundaries are presented as functions of the disk flexibility parameter. These boundaries reduce to the limiting case of a shaft containing a concentrated mass at the point of disk attachment when the disk's stiffness is very small, and approach the limiting case of an elastic shaft supporting a rigid disk as the stiffness increases.

79-1548

Flexible Shafts - Design and Use

O.H. Suhner
Suhner Manufacturing, Inc., Rome, GA, Power Transm. Des., 21 (5), pp 41-44 (May 1979) 9 figs, 1 table

Key Words: Flexible shafts, Design techniques

Flexible shafting is able to transmit rotary motion through a curved path, and can eliminate many shaft alignment and complex gearing problems. The article describes briefly the basic components of such shafts and presents a table for their selection and design.

BEAMS, STRINGS, RODS, BARS

79-1549

Out-of-Plane Vibrations of a Beam Including Non-Linear Inertia and Non-Linear Curvature Effects

M.R.M. Crespo Da Silva and C.C. Glynn
Dept. of Engrg. Science, Univ. of Cincinnati, Cincinnati, OH 45221, Intl. J. Nonlin. Mech., 13 (5/6), pp 261-271 (1978) 6 figs, 1 table, 13 refs

Key Words: Beams, Nonlinear theories, Perturbation theory, Harmonic excitation

The harmonic, non-linear response and its stability, for a clamped-clamped/sliding beam subject to a planar excitation is investigated by a perturbation method taking into account the *non-linear inertia and the non-linear curvature terms* in the differential equations of motion. The influence of excitation and beam parameters in the planar and in the non-planar response of the beam is determined in detail and *illustrated by several 'response charts.'*

79-1550

Propagation of Flexural Waves in Beams on Elastic Foundations

B.B. Prasad
Dept. of Civil Engrg., M.I.T., Muzaffarpur - 842 003,
Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 395-400, 7 figs, 4 refs

Key Words: Beams, Elastic foundations, Flexural vibration, Impact response, Interaction: soil-structure, Rotatory inertia effects

The propagation of flexural waves in beams on elastic foundations have been presented in detail in this paper and concepts such as phase and group velocities, which are often used for beams have been introduced for the first time for Euler-Bernoulli beam resting on Winkler model of elastic foundation.

79-1551

Parametric Response of Viscoelastically Supported Beams

H. Saito and K. Otomi
Dept. of Mech. Engrg., Tohoku Univ., Sendai, Japan,
J. Sound Vib., 63 (2), pp 169-178 (Mar 22, 1979) 6 figs, 4 refs

Key Words: Beams, Viscoelastic foundations, Mass-beam systems

The stability of viscoelastic beams with an attached mass and viscoelastic end supports under axial and tangential periodic loads is investigated. Viscoelastic end supports are substituted for translational and rotational springs with viscoelastic damping. The regions of instability for simple and combination resonances are obtained from the ordinary Mathieu equation which is obtained from the equation of motion by application of Galerkin's method. In numerical computations, the influences of the direction of loading, the attached mass, the support stiffness, and the damping on the regions of instability for simple and combination resonances are clarified.

79-1552

Determination of the Steady State Response of a Timoshenko Beam of Varying Cross-Section by Use of the Spline Interpolation Technique

T. Irie, G. Yamada, and I. Takahashi
Dept. of Mech. Engrg., Hokkaido Univ., Sapporo 060, Japan,
J. Sound Vib., 63 (2), pp 287-295 (Mar 22, 1979) 5 figs, 11 refs

Key Words: Beams, Variable cross section, Timoshenko theory, Periodic response, Internal damping

The steady state response of an internally damped Timoshenko beam of varying cross-section to a sinusoidally varying point force is determined by use of the spline interpolation technique.

79-1553

Torsional Vibrations of Short Thin-Walled Beams by FEM

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Structural Dynamics Group, Energy Systems & New Products Div., B.H.E.L., Vikas Nagar, Hyderabad - 500 593,
Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 433-436, 2 tables, 9 refs

Key Words: Beams, Torsional vibration, Finite element technique, Transverse shear deformation effects, Rotatory inertia effects

The present paper develops for the first time a finite-element model for the torsional vibrations of short wide-flanged doubly-symmetric thin-walled beams of open section including the effects of longitudinal inertia and shear deformation. New stiffness and mass matrices which include the second order effects are derived. Results are obtained for simply supported and clamped beams and are compared with the exact ones available in literature.

79-1554

Dynamic Crack Propagation in a Double Cantilever Beam

D. Shantaram
College of Engrg., Osmania Univ., Hyderabad - 500 007,
Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 389-394, 7 figs, 1 table, 6 refs

Key Words: Beams, Cantilever beams, Crack propagation

The paper describes analytical studies made by the author in the field of dynamic crack propagation in a double cantilever beam. While finite element method, using parabolic isoparametric elements have been used for spatial discretization, the dynamic equations of equilibrium are integrated using an explicit time marching scheme (second central difference). A special mass lumping technique applicable to parabolic elements is adopted.

79-1555

Whirling of a Base-Excited Cantilever Beam

M.W. Hyer
Dept. of Engrg. Science and Mechanics, Virginia Polytechnic Inst. and State Univ., Blacksburg, VA 24061, J. Acoust. Soc. Amer., 65 (4), pp 931-939 (Apr 1979) 13 figs, 16 refs

Key Words: Beams, Cantilever beams, Harmonic excitation, Whirling

The paper describes the response of a thin elastic cantilever beam excited by a known harmonic displacement at its base. The principal moments of the beam cross-sectional area are equal and the base excitation is in one of the principal directions. If the excitation frequency is slightly less than the resonant frequency of one of the bending modes, planar motions of the beam are unstable and an out-of-plane component of displacement develops.

79-1556

Forced Vibration of a Curved Beam with Viscous Damping

I. Sheinman
Faculty of Civil Engrg., Technion-Israel Inst. of Tech., Haifa, Israel, Computers Struc., 10 (3), pp 499-503 (June 1979) 10 figs, 3 refs

Key Words: Curved beams, Forced vibration, Viscous damping, Computer programs

A generalization of the dynamic solution for an arbitrary plane curved beam with viscous damping, under arbitrary load, is presented. The equation of motion, based on the linear theory, admits proportionality of the damping to the mass and stiffness matrices (Rayleigh damping). The numerical solution is obtained by direct time-integration, using backward differences (Houbolt's method). A general computer program (CURBEAM) was written for this purpose and a numerical example is presented.

79-1557

Vibration Characteristics of a Preheater Tower

A. Kumar and C. Rajkumar
Cement Research Inst. of India, New Delhi - 110 049, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 489-493, 6 figs, 2 tables, 6 refs

Key Words: Towers, Natural frequencies, Mode shapes, Seismic design

The frequencies and mode shapes of a typical preheater tower in a cement plant are obtained for its aseismic design. The complete structure, consisting of a set of reinforced concrete parallel frames, is substituted for its vibration analysis by a vertical shear beam with masses lumped at floor levels. The effect of flexibility of girders is taken into account as the stiffness properties of the shear beam are obtained from the equivalent column model developed for the complete structure.

79-1558

Comparative Evaluation of Wind and Seismic Loads for N.D. Cooling Tower

U.S.P. Verma, P.M. Akolkar, and A.S. Warudkar
Power Projects Engrg. Div., Dept. of Atomic Energy, Homi Bhabba Rd., Colaba, Bombay - 400 005, India, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 485-488, 3 figs, 5 tables

Key Words: Towers, Cooling towers, Shells, Wind-induced excitation, Seismic excitation

Wind and seismic loads are the primary loads on the shell of a natural draught hyperbolic cooling tower and the choice of appropriate criteria considering the safety and importance of the structure is a vital aspect in their design. A comparative evaluation of the seismic and wind loads on the shell of such cooling tower located on an alluvial site in a seismically active region has been presented in the paper.

79-1559

Dynamic Loads on Transmission Line Towers

R. Rangaswami, G. Jayaraman, A.R. Santhakumar, and T. Jayasekaran
Dept. of Structural Engrg., College of Engrg., Guindy, Madras 600 025, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 455-460, 3 figs, 1 table, 3 refs

Key Words: Towers, Transmission lines, Wind-induced excitation, Computer programs

In this paper a simplified method using condensed stiffness matrix for the solution of dynamic behavior of Transmission Line Towers is illustrated. Though the method decreases the number of degrees of freedom of the structure it preserves the kinematic and potential energies.

79-1560

Application of the Finite Element Method to Minimum Mass Design of a Bar with Two Specified Natural Frequencies

K. Wahizu and M. Hanaoka
Dept. of Aeronautics, Univ. of Tokyo, Tokyo, Japan,
Computers Struc., 10 (3), pp 539-545 (June 1979) 9 figs, 5 refs

Key Words: Bars, Minimum weight design, Natural frequencies, Finite element technique

In the first part of the present paper, a problem of minimum mass design of a bar with two specified longitudinal natural frequencies is treated. A discussion is given to whether the bar thus optimally designed has any other natural frequencies between the two specified natural frequencies or not. In the second part of the paper, an extension is made to a problem in which some inequality constraints on the mass distribution are also imposed. Optimality conditions for the inequality constraints are presented.

79-1561

Slack-Elasto-Plastic Dynamics of Cable Systems

D. Ma, J. Leonard, and K. Chu
Argonne National Lab., Argonne, IL,
ASCE J. Engr. Mech. Div., 105 (EM2), pp 207-222 (Apr 1979)

Key Words: Cables (ropes), Elastic plastic properties

A numerical procedure for determining the nonlinear dynamic response of cable systems is presented in which cable segments may be included as elastic, plastic, or buckled (slack) elements. Individual cable elements in the network are assumed either elastic, plastic, or slack, depending on the time history of load and system response. Finite element analogs are used as the basis for numerical modeling for spatial behavior.

79-1562

Parametric Investigations of Vibrating Cable Networks

L.F. Geschwindner, Jr. and H.H. West
Pennsylvania State Univ., University Park, PA,
ASCE J. Struc. Div., 105 (ST3), pp 465-479 (Mar 1979)

Key Words: Cables (ropes), Natural frequencies, Mode shapes

Natural frequencies and modes of vibration are determined for hyperbolic paraboloid cable networks composed of a linkage of straight members connected by frictionless pins with concentrated masses lumped at the connection points. The frequencies and mode shapes are determined through a QL transformation procedure using the linear equations of motion. A numerical problem is examined and the natural frequencies are presented. Six parameter studies are conducted to determine how the natural frequencies and mode shapes are altered in response to variations in scale factor, mass, applied force, modulus of elasticity, prestress, and sag.

BEARINGS

(Also see Nos. 1515, 1622, 1623)

79-1563

Measurement of Separator Contact Forces in Ball Bearings Using a Derotation Prism

L.J. Nypan
Dept. of Mechanics and Materials, School of Engrg., California State Univ., Northridge, Northridge, CA 91324,
J. Lubric. Tech., Trans. ASME, 101 (2), pp 180-188 (Apr 1979) 6 figs, 1 table, 6 refs

Key Words: Ball bearings, Experimental data, Dynamic tests

A derotation prism was used to produce a stationary image of balls deflecting a portion of the separator. Ball to cage contact forces in a 110 mm bearing at speeds to 12,000 rpm were found to be 25 N (five lb) maximum. Inner race land contact force was found to vary up to 20 N (four lb).

79-1564

Computer-Aided Design of Hybrid Conical Bearings

S.M. Rohde and H.A. Ezzat
Engrg. Mechanics Dept., General Motors Res. Labs., Warren, MI,
"Fundamentals of the Design of Fluid Film Bearings" presented at the Design Engrg. Conf., Chicago, IL, May 7-10, 1979, sponsored by the Lubrication Div. of ASME, pp 85-130, 4 figs, 8 refs

Key Words: Bearings, Periodic response, Computer programs, Computer-aided techniques

An analysis of the steady-state and dynamic characteristics of hybrid conical bearings is presented. The effect of bearing

misalignment and presence of drain grooves is considered. Potential turbulence in the recesses and its contribution to frictional power loss is also considered. In addition, an interactive computer package has been developed to implement the analysis for the design of hybrid bearings.

79-1565

Theoretical and Experimental Determination of the Dynamic Characteristics of a Hydrodynamic Journal Bearing

D..W. Parkins

Dept. for Design of Machine Systems, Cranfield Inst. of Tech., Cranfield, UK, J. Lubric. Tech., Trans. ASME, 101 (2), pp 129-136 (Apr 1979) 12 figs, 7 refs

Key Words: Journal bearings, Flexibility, Dynamic properties

This paper describes a theoretical and experimental investigation into the nonlinear characteristics of the eight coefficients which specify the lateral flexibility of a hydrodynamic journal bearing. Coefficient calculations allowed viscosity to vary with temperature, and pressure, and examined a range of positive and negative displacements and velocities. Experimental techniques have been developed in which coefficients were deduced from specially chosen, imposed vibration orbits arising from two mutually perpendicular external oscillating forces of variable relative magnitude and phase.

79-1566

Design of Journal Bearings for High Speed Rotating Machinery

P.E. Allaire

Dept. of Mech. & Aerospace Engrg., Univ. of Virginia, Charlottesville, VA, "Fundamentals of the Design of Fluid Film Bearings" presented at the Design Engrg. Conf., Chicago, IL, May 7-10, 1979, sponsored by the Lubrication Div. of ASME, pp 45-83, 24 figs, 5 tables, 11 refs

Key Words: Journal bearings, High speed rotors, Design techniques

Rotating machinery is commonly supported in fluid film hydrodynamic bearings. These bearings generally combine relatively low frictional resistance to turning with viscous damping to reduce lateral vibrations in the machines. Dynamic analysis of hydrodynamic bearings is concerned primarily with the forces developed in the bearing due to motions imposed on the shaft. Bearing analyses may be divided into three specific areas: steady-state, small amplitude linearized dynamic analysis, and large amplitude dynamic motions due to machine instability or large unbalance response. This study covers primarily the second two portions of bearing design.

79-1567

Design of Dynamically Loaded Journal Bearings

J.F. Booker

Dept. of Mech. & Aerospace Engrg., Cornell Univ., Ithaca, NY, "Fundamentals of the Design of Fluid Film Bearings" presented at the Design Engrg. Conf., Chicago, IL, May 7-10, 1979, sponsored by the Lubrication Div. of ASME, pp 31-44, 5 figs, 1 table, 17 refs

Key Words: Journal bearings, Design techniques, Reciprocating engines

Design criteria (chiefly film thickness and pressure) are suggested for dynamically loaded journal bearings. Practical means of prediction are cited, and a particular computation procedure (the mobility method) is examined in some detail. Applications in reciprocating machinery are reviewed together with correlation of predictions with field experience.

BLADES

79-1568

An Analysis of Viscous Effects on Unsteady Forces on Cascade Blades

Y. Tsujimoto, S. Murata, Y. Miyake, and F. Yamamoto

Faculty of Engrg. Science, Osaka Univ., Bull. JSME, 22 (165), pp 326-332 (Mar 1979) 19 figs, 5 refs

Key Words: Blades, Fluid-induced excitation

The effects of the fluid viscosity on the unsteady forces on cascade blades are investigated based on a linearized Navier-Stokes equation on the assumption that the perturbations are small. Also the sinusoidal dissipating gusts are introduced on the same assumption and the lift and drag response of the cascades to the flow and the forces on the up and down-

wards vibrating blades are calculated. It is found that the viscosity of the fluid works so as to enlarge the amplitude of the unsteady forces but it has not so much effect on the phase of the lifts.

79-1569

Research on the Flutter of Axial Turbomachine Blading

F. Sisto and R. Rossin

Dept. of Mech. Engrg., Stevens Inst. of Tech., Hoboken, NJ, Rept. No. ME-RT-78004, 31 pp (Nov 1978)

AD-A063 102/8GA

Key Words: Flutter, Turbomachinery blades

Typical aerodynamic moment and free flutter measurements are presented for thin airfoils in an annular cascade. For moment measurements, the parameters of significance were mean incidence angle, interblade phase angle and amplitude of oscillation. Since measurements take the form of a continuous record of moment versus angular position, the symbolic name "moment loops" is used. For the free flutter measurement, the parameters of interest were stagger angle, incidence angle, torsional amplitude, and reduced frequency. The characteristics of the experimental data are discussed and comparison is made with earlier tested thick blades.

79-1570

Performance of Rotating Cascades Under the Inlet-Distortions (1st Report, Performance Under the Radial Distortions)

A. Maekawa, T. Higashi, and S. Tanaka

Mitsubishi Heavy Ind. Co., Bull. JSME, 22 (165), pp 333-339 (Mar 1979) 13 figs, 2 tables, 13 refs

Key Words: Blades, Turbomachinery blades, Aerodynamic loads

Some experimental and theoretical studies of performances of rotating cascades operating under the radial-distortions are shown. The transmission of the distorted velocity profiles through the cascades, changes in characteristic curves and aerodynamic loading on the blade elements are obtained experimentally, and some discussions of the criterion of the onset of stall in the rotating cascades are made. The flow fields near the rotating cascades are analyzed by streamline curvature method and the results are compared with the experimental ones.

79-1571

Non-Linear Dynamic Response of a Wind Turbine Blade

I. Chopra and J. Dugundji

Dept. of Aeronautics and Astronautics, Massachusetts Inst. of Tech., Cambridge, MA 02139, J. Sound Vib., 63 (2), pp 265-286 (Mar 22, 1979) 23 figs, 17 refs

Key Words: Rotor blades, Turbine blades, Wind turbines, Flutter

The non-linear equations of motion for an isolated three-degree flap-lag-feather rotor blade under the action of a gravity field are derived, by using Lagrange's equations, for arbitrarily large angular deflections. Quasi-steady airfoil theory is used to obtain aerodynamic forces for sheared wind. A consistent set of non-linear equations are obtained by using non-linear terms up to the third order. The limit cycle analysis for forced oscillations as well as the determination of the principal parametric resonance of the blade due to periodic forces (from gravity and sheared wind) are performed by using the harmonic balance method and solving the resulting non-linear algebraic equations numerically by the Newton-Raphson iterative technique. The stability check of the non-linear solutions is carried out by using the perturbation technique and with the assumption of slowly changing functions.

79-1572

Experimental Evaluation of the Effect of Inlet Distortion on Compressor Blade Vibrations

J.F. Lubomski

NASA Lewis Research Ctr., Cleveland, OH, Rept. No. NASA-TM-79066; E-9882, 17 pp (1979)

N79-16300

Key Words: Compressor blades, Engine vibration, Experimental data

Compressor rotor strain gage data from an engine test conducted with an inlet screen distortion were reduced and analyzed. These data are compared to data obtained from the same engine without inlet pressure distortion to determine the net effect of the distortion on the vibratory response of the compressor blades.

CONTROLS

79-1573
What Designers Should Know About Wrap-Spring Clutches. Part II
L. LaPasso
Motion Control, Inc., Rockford, IL, Power Transm. Des., 21 (5), pp 45-48 (May 1979) 13 figs

Key Words: Clutches

Arguments for choosing wrap spring clutches over friction clutches for a drive system are presented. They are simpler to apply, require less input power, and generally give more accurate cycle times because they are insensitive to output torque. Generally, sprag-type clutches can replace friction clutches and provide more torque for the comparable clutch size.

CYLINDERS

79-1574
Acoustic Scattering by Circular Cylinders of Various Aspect Ratios
A. Maciulaitis
Research Dept., Grumman Aerospace Corp., Bethpage, NY, Rept. No. NASA-CR-3068, 54 pp (Jan 1979)
N79-16642

Key Words: Cylinders, Acoustic scattering

The effects of acoustic scattering on the useful frequency range of pressure gradient microphones were investigated experimentally between ka values of 0.407 and 4.232 using two circular cylindrical models (L/D = 0.5 and 0.25) having a 25 cm outside diameter.

DUCTS

79-1575
Propagation in a Liquid Layer Lying Over a Liquid Half-Space (Pekeris Cut)
H.P. Bucker
Naval Ocean Systems Ctr., San Diego, CA 92152, J. Acoust. Soc. Amer., 65 (4), pp 906-908 (Apr 1979) 1 fig, 10 refs

Key Words: Ducts, Sound propagation

Sound propagation in a uniform duct can be represented as a sum of normal modes plus a branch line integral(s) contribution. In the case of a homogeneous liquid layer lying over a homogeneous liquid half-space the complex modes exhibit a complicated migration as frequency is changed. In the case of a Pekeris branch cut this can result in the mode changing from a proper to an improper Riemann sheet or vice versa. This paper examines the migration of a typical mode and discusses a simple algorithm for calculating the Pekeris branch line integral.

79-1576
Sound Propagation in a Duct with Axial Sound Speed Variation: An Exact Solution
J.E. Cole, III
Cambridge Acoustical Assoc., Inc., 1033 Massachusetts Ave., Cambridge, MA 02138, J. Sound Vib., 63 (2), pp 237-246 (Mar 22, 1979) 7 figs, 4 refs

Key Words: Ducts, Sound propagation

The equation describing sound propagation in an ideal gas with exponential variation of static temperature in the direction of propagation is solved exactly in terms of known functions. Specific solutions for sound propagation in both infinite and semi-infinite length ducts with rigid walls are obtained. The alteration of the modal cut-off condition associated with an isothermal duct by the temperature variation is examined as well as the approach of other aspects of the solution to the familiar results for isothermal ducts. Comparison is also made with experimental data.

79-1577
Modal Propagation Angles in a Cylindrical Duct with Flow and Their Relation to Sound Radiation
E.J. Rice, M.F. Heidmann, and T.G. Sofrin
NASA Lewis Research Ctr., Cleveland, OH, Rept. No. NASA-TM-79030; E-9826, 12 pp (Jan 1979)
N79-15756

Key Words: Ducts, Elastic waves

The main emphasis of this article is upon the propagation angle with respect to the duct axis and its relation to the far-field acoustic radiation pattern.

79-1578

Modal Propagation Angles in Ducts with Soft Walls and Their Connection with Suppressor Performance

E.J. Rice

NASA Lewis Research Ctr., Cleveland, OH, Rept. No. NASA-TM-79081; E-9902, 16 pp (1979)

N79-16646

Key Words: Ducts, Modal analysis

The angles of propagation of the wave fronts associated with duct modes are derived for a cylindrical duct with soft walls (acoustic suppressors) and a uniform steady flow. The angle of propagation with respect to the radial coordinate (angle of incidence on the wall) is shown to be a better correlating parameter for the optimum wall impedance of spinning modes than the previously used mode cutoff ratio. Results from this approximate method were compared to exact modal propagation calculations to check the accuracy of the approximate method.

79-1579

Optimum Wall Impedance for Spinning Modes – A Correlation with Mode Cutoff Ratio

E.J. Rice

NASA Lewis Research Ctr., Cleveland, OH, J. Aircraft, 16 (5), pp 336-343 (May 1979) 13 figs, 18 refs

Key Words: Acoustic linings, Ducts, Acoustic impedance

A correlating equation relating the optimum acoustic impedance for the wall lining of a circular duct to the acoustic mode cutoff ratio is presented and compared to exact calculations. The optimum impedance was correlated with cutoff ratio because the cutofff ratio appears to be the fundamental parameter governing the propagation of sound in the duct. Modes with similar cutoff ratios respond in a similar way to the acoustic liner.

79-1580

Optimized Multisectioned Acoustic Liners

K.J. Baumeister

NASA Lewis Research Ctr., Cleveland, OH, Rept. No. NASA-TM-79028; E-9823, 17 pp (1979)

N79-15759

Key Words: Acoustic linings, Ducts, Computer programs

New calculations show that segmenting is most efficient at high frequencies with relatively long duct lengths where the attenuation is low for both uniform and segmented liners. Statistical considerations indicate little advantage in using optimized liners with more than two segments while the bandwidth of an optimized two-segment liner is shown to be nearly equal to that of a uniform liner.

FRAMES, ARCHES

79-1581

Dynamic Structural Synthesis

A. Rajaraman and C.V. Vaidyanathan

Structural Engrg. Research Centre, Madras, India, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 407-412, 3 figs, 20 refs

Key Words: Machine foundations, Supports, Frames, Structural synthesis, Seismic response

Design of structures in the dynamic/seismic response regime is always involved rather than the corresponding one under static loads. The object of the present study is to investigate the structural synthesis of frames supporting machines transmitting dynamic loads. A brief review of the work done in the past towards structural synthesis in the dynamic domain is given and the problem is formulated in terms of the dimensions of the members as design variables.

79-1582

Optimum Seismic-Resistant Design of R/C Frames

S.W. Zagajeski and V.V. Bertero

Colorado State Univ., Fort Collins, CO, ASCE J. Struc. Div., 105 (ST5), pp 829-845 (May 1979)

Key Words: Frames, Reinforced concrete, Computer-aided techniques, Seismic design, Modal analysis

The procedure is based on a computer-aided iterative technique. It consists of two main phases: a preliminary design phase, which is repeated until an acceptable preliminary design is obtained; and a final design phase. Seismic design forces are found from an inelastic design spectrum employing a modal analysis technique. A weak-girder strong column design criterion is imposed and member design is based on a story-wise optimization procedure using a linear programming technique.

GEARS

79-1583
Multiport Models for the Kinematic and Dynamic Analysis of Gear Power Transmissions
R.R. Allen
Mechanics and Structures Dept., Univ. of California, Los Angeles, CA 90024, J. Mech. Des., Trans. ASME, 101 (2), pp 258-267 (Apr 1979) 17 figs, 24 refs

Key Words: Gears, Power transmission systems, Bond graph techniques

The kinematics of a gear power transmission may be characterized by a power-conserving kinematic transformation between independent and dependent angular velocities. The conjugate of this transform provides a relation between input and output torques. A bond graph multiport representing these kinematic relations provides a power-conserving core to which dissipative, inertial, and compliance effects may be added. This dynamic model of a power transmission may be connected with other machine elements (such as other kinematic mechanisms, motors, driveshafts, and loads) to form large-scale, computable dynamic models.

79-1584
Transmission Errors and Noise of Spur Gears Having Uneven Tooth Profile Errors
I. Yuruzume, H. Mizutani, and T. Tsubuku
Mech. Engrg. Lab., Tokyo, Japan, J. Mech. Des., Trans. ASME, 101 (2), pp 268-273 (Apr 1979) 13 figs, 8 refs

Key Words: Gear noise, Transmission gears

The problems of involute spur gear noise and transmission errors are studied by meshing spur gears. Five kinds of tooth profile errors, such as convex, concave and wavelike, were formed on the test gear teeth by grinding. The value of each tooth profile error is divided into 3 grades, according to the Gear standards of JIS. Transmission errors of 15 test gears and a master gear were measured by a single flank gear rolling tester with a planetary gear system. Gear noise and strains near tooth fillets were measured by running these test gears on a gear noise testing machine with a power absorbing system, in an anechoic room. This paper presents experimental results and studies of the influence of tooth profile error forms on single flank rolling errors, situation of tooth contacts and gear noise while running.

LINKAGES

79-1585
Hydrodynamic Adjustable-Speed Drives
H.J. Langlois
Fluid Drive Engrg., American-Standard, Detroit, MI, Power Transm. Des., 21 (5), pp 60-62 (May 1979) 6 figs, 2 tables

Key Words: Couplings

The operation, application, and advantages of fixed-fill and adjustable-fill fluid couplings is described.

79-1586
Fabric-Reinforced Rubber Expansion Joints
E. Holland
Goodall Rubber Co., Trenton, NJ, Plant Engrg., 33 (10), pp 151-154 (May 17, 1979) 5 figs, 2 tables

Key Words: Expansion joints, Elastomers

In the article rubber expansion joints are recommended for piping systems operating at temperatures of less than 250 F. They allow better movement in straight piping runs, protect piping from thermal expansion reactions, dampen pump-induced vibration pulses, and improve overall operation of piping systems.

79-1587
Force System Structural Synthesis by Using Coupler Curves and Interactive Computer Graphics
W.L. Carson and R.S. Haney
Mech. and Aerospace Engrg., Univ. of Missouri-Columbia, Columbia, MO 65211, J. Mech. Des., Trans. ASME, 101 (2), pp 232-237 (Apr 1979) 8 figs, 1 table, 5 refs

Key Words: Structural synthesis, Four bar mechanisms, Data display, Graphic methods

An interactive computer graphics program has been developed to structurally synthesize force systems which will drive a 4R-4Bar linkage to have a desired dynamic motion time response. The program is also useful for iterative dimen-

sional synthesis. The program contains a coupler curve "boxing" technique to help the designer identify generalized force "characteristic" curve shapes for translational force elements between nonadjacent links. Some general observations about generalized force "characteristic" curve shapes are also presented.

79-1588

Generalized Force Curve Shapes for Structural Synthesis of Joint Torque Systems to Produce a Desired Dynamic Motion Time Response of a 4R-4Bar

W.L. Carson and R.S. Haney

Mech. and Aerospace Engrg., Univ. of Missouri-Columbia, Columbia, MO 65211, J. Mech. Des., Trans. ASME, 101 (2), pp 238-245 (Apr 1979) 8 figs, 1 table, 9 refs

Key Words: Structural synthesis, Curve fitting, Four bar mechanisms

Synthesis of a force system which will drive a linkage to have a desired dynamic motion-time response is basically a task of curve fitting the generalized force curve equation, GFS, of a force system to the generalized force, DGF, required to drive the mechanism. The paper presents a summary of characteristic curve shapes for joint torque in a 4R-4Bar crank-rocker mechanism, the influence of parameters on these curves, and an illustrative example of structural synthesis.

79-1589

Partial Dynamic State Synthesis by Use of Mass Parameters in a System Coupler Link

J.L. Elliott, D. Tesar, and G.K. Matthew

Dept. of Mech. Engrg., Univ. of Florida, Gainesville, FL, J. Mech. Des., Trans. ASME, 101 (2), pp 246-249 (Apr 1979) 3 figs, 1 table, 6 refs

Key Words: Structural synthesis, Mass coefficients, Optimization

One of the primary objectives of synthesis is the reduction of the number of controlling parameters facing the designer in the optimization phase of the design process while at the same time forcing the remaining parameters to generate solutions which are acceptable in some prescribed sense. In this paper, the four mass parameters m, k, u, v of any link moving in coplanar motion are used to meet specified torque (or energy) levels or specified shaking moment values for up to four positions of the system.

MECHANICAL

79-1590

Determination of the Critical Operating Speeds of Planar Mechanisms by the Finite Element Method Using Planar Actual Line Elements and Lumped Mass Systems

S. Kalaycioglu and C. Bagci

Packaging Machinery, Redington, Inc., Bellwood, IL 60104, J. Mech. Des., Trans. ASME, 101 (2), pp 210-223 (Apr 1979) 21 figs, 38 refs

Key Words: Plane mechanism, Critical speed, Finite element technique

It has been a well-established fact that dynamic systems in motion experience critical speeds, such as rotating shafts and geared systems whose undeformed reference geometry remain the same at all times. Their critical speeds are determined by their natural frequencies of considered type of free vibrations. Linkage mechanisms as dynamic systems in motion change their undeformed geometries as function of time during the cycle of kinematic motion. They also experience critical operating speeds as rotating shafts and geared systems do, and their critical speeds are determined by the minima of their natural frequencies during a cycle of kinematic motion. The natural frequencies of the mechanism and the corresponding mode vectors (mode deflections) are determined as the eigenvalues and eigenvectors of the equations of instantaneous-position-free-motion of the mechanism. Method is formulated to include or exclude the link axial deformations, and apply to any number of loops having any type of planar pair. Critical speeds of planar four-bar slider-crank, and Stephenson's six-bar mechanisms are determined. Experimental results for the four-bar mechanism are given. Effect of axial deformations and link rotary inertias are investigated.

PANELS

(See No. 1624)

PIPES AND TUBES

(Also see No. 1505)

79-1591

Lifeline Engineering Approach to Seismic Qualification

T.L. Anderson and D.J. Nyman

Fluor Engrs. and Constructors, Inc., Irvine, CA, ASCE, J. Technical Councils, 105 (TC1), pp 149-161 (Apr 1979)

Key Words: Seismic design, Piping systems

Equipment qualification to meet seismic design requirements has become an important consideration in lifeline earthquake engineering. The most notable non-nuclear project to date where seismic qualification was a major consideration is the trans-Alaska Pipeline System (Alyeska Project). The approach used for equipment qualification, as developed and employed on the Alyeska Project, is described. Considerable flexibility permitted development of a cost-effective and schedule-accommodating program. Major problems encountered are identified, the approach used to solve these problems is described, and a set of recommended guidelines for future projects is given. The analyses of the Alyeska approach includes the project seismic criteria, description of the performance-based specification strategy for resolving problems, and the continuous tracking of qualification progress.

79-1592

Seismic Design of Oil Pipeline Systems

R.P. Kennedy and S.A. Short

Engrg. Decision Analysis Co., Inc., Irvine, CA, ASCE, J. Technical Councils, 105 (TC1), pp 119-134 (Apr 1979)

Key Words: Seismic design, Piping systems

An overview of seismic design of oil pipeline systems is presented including the performance of petroleum transmission systems during past earthquakes, a dual level seismic design philosophy that is recommended for these systems, geotechnical investigations needed to define design loads induced by seismic hazards, and design approaches for buried pipeline. Based on the dual seismic design philosophy the pipeline system is designed to minimize the possibility of oil spillage during an earthquake that has a low probability of occurrence and to remain operational after an earthquake that has a reasonable probability of affecting the pipeline system during its life. Design approaches for buried pipeline at fault crossings or in zones of potential liquefaction are available by which pipelines can be designed to minimize the possibility of rupture resulting from large differential soil displacements due to fault movement of liquefaction.

79-1593

State of the Art of Buried Lifeline Earthquake Engineering

L.R. Wang and M.J. O'Rourke

Rensselaer Polytechnic Inst., Troy, NY, Rept. No. NSF/RA-770702, 17 pp (1977)

PB-291 601/3GA

Key Words: Pipelines, Underground structures, Seismic design, Earthquake resistant structures

State-of-the-art information is presented on the behavior and design of buried water/sewer lifelines subjected to earthquakes.

79-1594

Seismic Design Criteria for Buried Pipelines. (Seismic Vulnerability, Behavior and Design of Underground Piping Systems)

L.R. Wang and R.C. Fung

Dept. of Civil Engrg., Rensselaer Polytechnic Inst., Troy, NY, Rept. No. NSF/RA-780343, 23 pp (Sept 1978)

PB-291 415/8GA

Key Words: Pipelines, Underground structures, Seismic design, Earthquake resistant structures

Overall aims of this research are to develop a systematic way of assessing the adequacy and vulnerability of water/sewer distribution systems subjected to seismic loads and to develop future design methodologies. To aid in the design of buried pipelines against earthquakes, this paper evaluates the reserve strength of buried pipes beyond normal stress/strain conditions.

79-1595

Earthquake Response of Buried Pipelines. (Seismic Vulnerability, Behavior and Design of Underground Piping Systems)

M.J. O'Rourke and L.R. Wang

Dept. of Civil Engrg., Rensselaer Polytechnic Inst., Troy, NY, Rept. No. NSF/RA-780340, 17 pp (Mar 1978)

PB-291 412/5GA

Key Words: Piping systems, Underground structures, Seismic response, Seismic design, Earthquake resistant structures

Overall aims of this research are to develop a systematic way of assessing the adequacy and vulnerability of water/

sewer distribution systems subjected to seismic loads and also to develop future design methodologies for water/sewer systems. Because of the geographical extent of buried pipelines, analysis and design procedures for buried pipelines are quite different than the standard procedures developed for building type structures. The purpose of this paper is to investigate the following assumptions which form the basis for the presently available seismic design procedures for buried pipelines subjected to ground shaking.

79-1596

Seismic Response Behavior of Buried Pipelines (Seismic Vulnerability, Behavior and Design of Underground Piping Systems)

L.R. Wang and K. Cheng

Dept. of Civil Engrg., Rensselaer Polytechnic Inst., Troy, NY, Rept. No. NSF/RA-780341, 16 pp (June 1978)

PB-291 413/3GA

Key Words: Piping systems, Underground structures, Seismic response, Earthquake damage

Overall aims of this research are to develop a systematic way of assessing the adequacy and vulnerability of water/sewer distribution systems subjected to seismic loads and also to develop future design methodologies for water/sewer systems. This paper reports pipeline damages caused by earthquake excitations in the longitudinal direction of a pipeline have been observed to be a major mode of failure. A simplified quasi-static seismic deformation analysis neglecting the dynamic terms for buried pipelines subjected to earthquake motions in the axial direction is proposed.

79-1597

Seismic Vulnerability of the Latham Water Distribution System. A Case Study (Seismic Vulnerability, Behavior and Design of Underground Piping Systems)

R.R. Pikul, L.R. Wang, and M.J. O'Rourke

Dept. of Civil Engrg., Rensselaer Polytechnic Inst., Troy, NY, Rept. No. NSF/RA-780342, 42 pp (Sept 1978)

PB-291 414/1GA

Key Words: Piping systems, Underground structures, Seismic response, Earthquake damage, Vulnerability

Overall aims of this research are to develop a systematic way of assessing the adequacy and vulnerability of water/sewer distribution systems subjected to seismic loads and to develop future design methodologies. This case study applies state-of-the-art earthquake engineering techniques plus the results of current research developed during the SVBDUPS Project to assess the potential vulnerability to earthquakes of the distribution piping system of the Latham Water District, Albany County, New York.

79-1598

Seismic Risk Analysis of Latham Water District, Albany, New York (Seismic Vulnerability, Behavior and Design of Underground Piping Systems)

M.J. O'Rourke and E. Solla

Dept. of Civil Engrg., Rensselaer Polytechnic Inst., Troy, NY, Rept. No. NSF/RA-770703, 65 pp (June 1977)

PB-291 411/7GA

Key Words: Piping systems, Underground structures, Seismic response, Vulnerability

Overall aims of this research are to develop a systematic way of assessing the adequacy and vulnerability of water/sewer distribution systems subjected to seismic loads and also to develop future design methodologies for water/sewer systems. As a first step in developing a systematic way of assessing the adequacy of the Latham Water Distribution System to seismic excitation, this report determines the seismic risk of the Albany area. Richter's relationship and the average occurrence rate for the Albany, New York area is established from available data of earthquakes in the Northeast.

79-1599

Seismic Analysis of Steam Generator & PHT System

S.K. Shrivastava, M.M. Manna, U.S.P. Verma, K.G. Bhatia, and A.K. Singh

P.P.E.D., Dept. of Atomic Energy, Colaba, Bombay 400005, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 329-334, 3 figs, 5 tables, 3 refs

Key Words: Nuclear power plants, Seismic excitation, Boiler tubes, Boilers, Tubes, Computer programs

A detailed seismic analysis of vital equipment and piping system in a Nuclear Power Plant (NPP) becomes essential to ensure the safety of the plant under seismic conditions. The steam generator and the primary heat transport system

being a critical system, its detailed seismic analysis has been performed. The paper describes a three dimensional seismic analysis of steam generator/PHT system in which the steam generator, piping system, coolant pump and reactor headers all have been included in a single mathematical model.

79-1600

Dynamic Behaviour of Inter-Connected Co-Axial Tubes Surrounded by Fluid

A.R. Chandrasekaran and D.K. Paul

Dept. of Earthquake Engrg., Univ. of Roorkee, U.P., India, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 461-464, 4 figs, 4 tables, 1 ref

Key Words: Tubes, Pipes (tubes), Fluid induced excitation

In a number of equipments, the dynamic behavior of coaxial pipes and tubes which form a part of it are of importance. Sometimes these tubes are interconnected with each other by spacers and also surrounded by fluid. In this study, the behavior of coaxial cylindrical tubes are investigated. These tubes are considered fixed at the ends and they may also be connected with each other at certain locations by spacers.

79-1601

The Transmission of Sound Waves Through Water in a PFR Subassembly Wrapper

M.A. Domis and M.H. Butterfield

United Kingdom Atomic Energy Authority, AEE Winfrith, Dorchester, Dorset, UK, J. Sound Vib., 63 (2), pp 247-258 (Mar 22, 1979) 10 figs, 10 refs

Key Words: Tubes, Nuclear reactor components, Cooling systems, Sound transmission, Mathematical models

A theoretical model is used to analyze the reduction in the speed of longitudinal waves in flexible tubes of arbitrary cross-section at low frequencies. The model is in good agreement with an experiment involving a PFR subassembly wrapper immersed in a water tank.

PLATES AND SHELLS

(Also see No. 1558)

79-1602

Amplitude-Frequency Characteristics of Non-Linear Vibrations of Clamped Elliptic Plates Carrying a Concentrated Mass

B.M. Karmakar

Government Engrg. College, Jalpaiguri, West Bengal, India, Intl. J. Nonlin. Mech., 13 (5/6), pp 351-359 (1978) 1 fig, 5 refs

Key Words: Plates, Flexural vibration

The influence of a concentrated mass on the amplitude-frequency characteristics of large amplitude-transverse vibrations of an isotropic clamped elliptic plate has been investigated by the application of the von Karman equations.

79-1603

Non-Linear Vibrations of Transversely Isotropic Rectangular Plates

G. Prathap and K.A.V. Pandalai

Fibre Reinforced Plastics Research Centre and Dept. of Aeronautical Engrg., IIT Madras, India, Intl. J. Nonlin. Mech., 13 (5/6), pp 285-294 (1978) 5 figs, 14 refs

Key Words: Rectangular plates, Flexural vibration, Free vibration, Transverse shear deformation effects, Rotatory inertia effects

The large amplitude free flexural vibration of transversely isotropic rectangular plate, incorporating the effects of transverse shear and rotatory inertia, is studied using the von Karman field equations. A mode shape, consisting of three generalized-coordinates together with the Galerkin technique, results in a system of three non-linear simultaneous ordinary differential equations which govern the motion of the plate. These equations are integrated using a fourth-order Runge-Kutta method to obtain the period for each amplitude of vibration. The results are compared with earlier results which were based on a one-term or one generalized coordinate solution and using the Berger approximation or the von Karman field equations.

79-1604

Effects of Large Amplitude, Shear and Rotatory Inertia on Vibration of Rectangular Plates

M. Sathyamoorthy
Dept. of Civil Engrg., The Univ. of Calgary, Calgary, Alberta, Canada, J. Sound Vib., 63 (2), pp 161-167 (Mar 22, 1979) 3 figs, 1 table, 9 refs

Key Words: Plates, Rectangular plates, Transverse shear deformation effects, Rotatory inertia effects

In this paper, the governing equations applicable for the large amplitude free, flexural vibration of orthotropic rectangular plates are formulated in terms of the displacement components. The formulation and the solutions presented for the cases of isotropic and orthotropic simply supported rectangular plates incorporate the effects of the transverse shear deformation and the rotatory inertia on the large amplitude vibration behavior. The influences of shear and rotatory inertia are significant in the case of moderately thick plates undergoing large amplitude vibration.

79-1605

Non-Linear Dynamic Response of Rectangular Plates Subjected to Transient Loads

Y. Nath
Dept. of Appl. Mechanics, Motilal Nehru Regional Engrg. College, Allahabad-211004, India, J. Sound Vib., 63 (2), pp 179-188 (Mar 22, 1979) 4 figs, 9 refs

Key Words: Plates, Rectangular plates, Pulse excitation, Transient response

The non-linear dynamic responses of both clamped and simply supported rectangular plates have been investigated for uniform pulse loadings. The non-linear partial differential equations have been linearized by expressing one or more of the product terms constituting the non-linearity in the differential equations in Taylor's series. By using a finite difference scheme for space-wise and the Houbolt scheme for time-wise integrations, the differential equations are transformed into a set of linear algebraic equations which has been solved by matrix methods without using any iterative techniques. The numerical results obtained by the present technique compare well with the results available in the literature. In addition, the influence of damping on the non-linear dynamic response has been studied.

79-1606

A Comparison of Lagrangian and Serendipity Mindlin Plate Elements for Free Vibration Analysis

E. Hinton and N. Bicanic
University College, Swansea, Wales, Computers Struc., 10 (3), pp 483-493 (June 1979) 10 figs, 1 table, 25 refs

Key Words: Plates, Free vibration

The performance of five Lagrangian and Serendipity (4, 8, 9, 12, and 16 noded) isoparametric elements in the free vibration finite analysis of Mindlin plates is evaluated. The results are compared with well established analytical and numerical solutions based on Mindlin's thick plate theory and three dimensional elasticity solutions.

79-1607

The Free and Forced Waves on a Fluid-Loaded Elastic Plate

D.G. Crighton
Dept. of Appl. Mathematical Studies, The Univ. of Leeds, Leeds LS2 9JT, UK, J. Sound Vib., 63 (2), pp 225-235 (Mar 22, 1979) 2 figs, 12 refs

Key Words: Plates, Fluid-induced excitation

The often-studied problem of the response of a fluid-loaded thin elastic plate to external forcing is considered again, with the aim of determining those "free waves" of the coupled system which can actually be excited.

79-1608

Response of Plate to Nonstationary Random Load

G. Ahmadi and M.A. Satter
Dept. of Mech. Engrg., Pahlavi Univ., Shiraz, Iran, J. Acoust. Soc. Amer., 65 (4), pp 926-930 (Apr 1979) 23 refs

Key Words: Plates, Rectangular plates, Random excitation, Correlation technique, Cross correlation technique

The response of a rectangular plate subjected to nonstationary random load is studied. The general expressions for the autocorrelation and the mean square displacement are derived and discussed. Similar study was carried out for the stress components. The random excitation is then assumed to be a modulated white noise or narrow-band process.

79-1609

Asymmetric Vibrations of Polar Orthotropic Laminated Annular Plates

I. Elishakoff and Y. Stavsky

Technion-Israel Inst. of Tech., Haifa, Israel, AIAA J., 17 (5), pp 507-513 (May 1979) 9 figs, 1 table, 26 refs

Key Words: Plates, Circular plates, Layered materials, Axisymmetric vibrations, Asymmetry

A theory of general nonsymmetric motion of heterogeneous orthotropic annular plates in terms of radial, circumferential, and transverse displacements is formulated. Numerous examples are presented indicating the effect of plate heterogeneity on the vibration spectrum. An interesting feature is that the density of the eigenfrequencies in laminated plates may be higher than that of the homogeneous plates.

79-1610

Vibratory Response of a Rotating Disk Incorporating Image Derotation Techniques and Holographic Interferometry

J.E. Horner, J.C. MacBain, and W.A. Strange

Air Force Aero Propulsion Lab., Wright-Patterson AFB, OH, Rept. No. AFAPL-TR-78-62, 62 pp (Sept 1978)

AD-A062 671/3GA

Key Words: Rotating structures, Disks (shapes), Holographic techniques, Interferometers, Experimental data, Computer programs

This report covers work carried out at AFAPL's Turbo Structures Research Laboratory (TSRL) on the vibratory response of an internally clamped annular disk under both static and rotational conditions. Standard holographic interferometry was used to experimentally determine the frequencies and mode shapes of a 10 inch disk under non-rotating conditions.

79-1611

Refined Theory of Damped Axisymmetric Vibrations of Double-Layered Cylindrical Shells

S. Markus

Inst. of Machine Mechanics, Slovak Academy of Sciences, Bratislava, Czechoslovakia, J. Mech. Engr. Sci., 21 (1), pp 33-37 (Feb 1979) 3 figs, 8 refs

Key Words: Cylindrical shells, Vibration damping, Axisymmetric vibrations

The governing differential equations of vibrations of double-layered cylindrical shells are derived from classical thin-shell theory. The outer layer of the shell is assumed to be visco-elastic, possessing high damping capacity to control vibrations. Decoupled torsional and coupled radial-longitudinal vibration modes are analyzed by the method of damped normal modes. The present theory refines Kagawa and Krokstad's former analysis.

79-1612

Isolation of the Resonant Component in Acoustic Scattering from Fluid-Loaded Cylindrical Shells

J.D. Murphy, J. George, and H. Überall

3709 Merlin Way, Annandale, VA 22003, Wave Motion, 2 (1), pp 141-147 (Apr 1979) 5 figs, 9 refs

Key Words: Cylindrical shells, Shells, Submerged structures, Wave diffraction, Elastic waves

For the problem of scattering of a plane acoustic wave by a cylindrical elastic shell immersed in a fluid, it is demonstrated that a recently proposed "intermediate background" formalism serves to separate the resonant component from the nonresonant background in the scattering amplitude. Numerical calculations are performed for the case of an air-filled aluminium shell in water.

79-1613

An Engineering Approach to Calculating the Lowest Natural Frequencies of Thin Conical Shells

E.H. Jager

Studiengruppe Ballistik , Messerschmitt - Bolkow - Blohm GmbH, D-8898 Schrobenhausen, Germany, J. Sound Vib., 63 (2), pp 259-264 (Mar 22, 1979) 3 figs, 2 tables, 6 refs

Key Words: Shells, Conical shells, Natural frequencies, Vibration measurement, Resonance bar technique

The lowest natural frequencies of various hollow cones have been measured by a noncontact resonance technique. On the basis of the results, a semi-empirical formula has been derived for the natural frequencies of hollow cones supported at their apex. The results may also, to some extent, be useful in estimating the lowest natural frequencies of bells.

79-1614

Transient Response of Two Fluid-Coupled Spherical Elastic Shells to an Incident Pressure Pulse

H. Huang
Naval Research Lab., Washington, D.C. 20375, J. Acoust. Soc. Amer., 65 (4), pp 881-887 (Apr 1979) 7 figs, 12 refs

Key Words: Shells, Spherical shells, Concentric structures, Transient response

The transient response of a system of two initially concentric spherical elastic shells coupled by an ideal fluid and impinged upon by an incident plane pressure pulse is analyzed. The classical techniques of separation of variables and Laplace transforms are employed for solving the wave equations governing the fluid motions and the shell equations of motion. A scheme of iterative convolution was devised for the inversion of the Laplace transforms that facilitates the calculation of accurate transient solutions of the response of the shells. A sample calculation of shell responses was performed and results are compared to the case in which the outer shell is absent.

STRUCTURAL

79-1615

Soil Seismic Pressure on Retaining Walls

P.I. Yakovlev and A.V. Shkola
Odessa Engrg. Inst. of Merchant Marine, 34, Mechnikov St., Odessa, USSR, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 271-276, 3 figs, 4 refs

Key Words: Walls, Seismic excitation

The problem of non-cohesive soil pressure upon inclined displacing rough walls under the action of seismic forces calculated according to the static theory is analyzed.

79-1616

Investigation of R.C.C. Planar and Space Shear Walls

Y.P. Gupta and A.K. Basak
Civil Engrg. Dept., Univ. of Sulaimaniha, Iraq, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 317-322, 6 figs, 2 tables, 6 refs

Key Words: Walls, Reinforced concrete, Dynamic response, Seismic response

Experimental results are presented on planar and space reinforced concrete shear walls subjected to in-plane lateral and diagonally applied loading. Experimentally determined stiffness in terms of load-displacement hysteresis curves and also dynamic properties are presented.

79-1617

Performance of Modified Beam Matrices for the Dynamic Analysis of Coupled Shear Walls

V. Kumar, A.D. Pandey, and S.P. Gupta
Dept. of Earthquake Engrg., Univ. of Roorkee, U.P., India, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 311-316, 2 figs, 4 tables, 6 refs

Key Words: Beams, Walls, Matrix methods, Dynamic response

The performance of four different modified beam matrices for the dynamic analysis of coupled shear walls is studied under constraints of solution techniques, number of iterations and accuracy of the evaluated roots.

79-1618

Reliability of Retaining Structures During Earthquakes

D. Athanasiou-Grivas
Dept. of Civil Engrg., Rensselaer Polytechnic Inst., Troy, NY 12181, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 265-270, 9 figs, 2 tables, 12 refs

Key Words: Walls, Retaining walls, Seismic response

The objectives of this study are to provide an expression for the pressure acting on a retaining wall during an earthquake, and to determine the probability of failure of the wall through an application of the combinatory reliability analysis.

79-1619
Seismic Behavior of Gravity Retaining Walls
R. Richards, Jr. and D.G. Elms
Univ. of Delaware, Newark, DE, ASCE J. Geotech. Engr. Div., 105 (GT4), pp 449-464 (Apr 1979)

Key Words: Walls, Seismic response

The paper shows that in order to use the quasi-static Mononobe-Okabe analysis for the prediction of earthquake dynamic forces on a gravity retaining wall, wall inertia effects must be included. A design procedure is developed in which the designer chooses an acceptable level of wall displacement: he then computes the design wall weight which will restrict displacement in an earthquake to the predetermined level.

79-1620
Experiments on Corbels Subjected to Cyclic Loads
M. Lakshmipathy and A.R. Santhakumar
Dept. of Civil Engrg., College of Engrg., Guindy, Madras, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 339-344, 5 figs, 1 table, 8 refs

Key Words: Structural members, Periodic excitation, Experimental data, Seismic excitation

This paper describes the results of an experimental study on reinforced as well as reinforced fibrous concrete corbels subjected to static, static cyclic and static reversed cyclic loading. Attention is focused on the ductility, stiffness degradation and energy absorption characteristics of these members. Provision of vertical stir-ups helps in reducing the service load deflection and in increasing the ultimate ductility.

SYSTEMS

ABSORBER

79-1621
Full-Scale Engine Tests of Bulk Absorber Acoustic Inlet Treatment
L.J. Heidelberg and L. Homyak
NASA Lewis Research Ctr., Cleveland, OH, Rept. No. NASA-TM-79079; E-9899, 16 pp (1979)
N79-16645

Key Words: Absorbers (materials), Noise reduction, Engine noise

Three different densities of Kevlar bulk absorber fan inlet treatment were tested on a YF 102 turbofan engine. Far-field noise measurements were made and the attenuation properties of the three treatment densities were compared. In addition, the best bulk treatment was compared to the best single degree of freedom, SDOF (honeycomb and perforated cover sheet) treatment from another investigation.

NOISE REDUCTION
(See No. 1579)

ACTIVE ISOLATION

79-1622
The Active Magnetic Bearing
D. Cameron
Power Transm. Des., 21 (5), pp 54-55 (May 1979) 7 figs

Key Words: Bearings, Magnetic bearings, Active isolation

New bearings support rotating shafts with magnetic fields. Shaft and bearing never make contact, and electronic controls actively adjust the supporting magnetic fields to accurately maintain rotor position despite changing loads. These active bearings are now being used on high-precision European machine tools.

79-1623
Developments in Active Magnetic Bearings Offer New Choices for Rotating Equipment
W. O'Keefe
Power, 123 (5), p 107 (May 1979) 4 figs

Key Words: Bearings, Magnetic bearings, Active isolation

Added expense of electronic control can be offset by energy savings and absence of lubrication. Recent advances in solid-state switching have been a factor in increase in load capacity to figures interesting for pumps, fans, and small turbines.

79-1624
The Use of Panel Methods with a View to Problems in Aircraft Dynamics
T.E. Labrujere, R. Roos, and L.J.J. Erkelens
National Aerospace Lab., Amsterdam, Netherlands, In: Von Karman Inst. for Fluid Dyn., Aerodyn. Inputs for Probl. in Aircraft Dyn., Vol. 2, 140 pp (1977)
N79-15916

Key Words: Panels, Aircraft, Dynamic stability

A survey is given of the basic principles of the panel methods. The most frequently used methods, steady as well as unsteady, are described in some detail. Recent developments aiming at improvement and extension of the range of applicability are reviewed. The use of panel methods for the determination of stability derivatives is discussed. Results of some applications are shown illustrating the capability of the panel methods.

79-1625
Aircraft Motion Sensitivity to Variations in Dynamic Stability Parameters
R.W. Butler and T.F. Langham
ARO, Incorporated, Arnold Air Force Station, TN, In: AGARD Dyn. Stability Parameters, Nov 1978, 11 pp
Sponsored by the Air Force
N79-15095

Key Words: Aircraft, Dynamic stability

A 6-DOF nonlinear and 5-DOF linearized dynamic sensitivity study was conducted on a fighter/bomber and attack type aircraft.

79-1626
Lateral-Longitudinal Cross-Coupling Effects
J. Sandford
Von Karman Inst. for Fluid Dynamics, Rhode-Saint-Genese, Belgium, In: its Aerodyn. Inputs for Probl. in Aircraft Dyn., Vol. 1, 1977, 29 pp (for primary document see N79-15907)
N79-15912

Key Words: Aircraft, Lateral vibration, Longitudinal vibration

The conditions under which the equations of motion for an aircraft can be separated into lateral and longitudinal groups are first established. The various ways in which these conditions can be violated are then discussed with particular reference to those which are aerodynamic in origin.

79-1627
An Analytic Theory of Supersonic/Hypersonic Stability at High Angles of Attack
W.H. Hui
Dept. of Appl. Mathematics, Waterloo Univ., Ontario, Canada, In: AGARD Dyn. Stability Parameters, Nov 1978, 9 pp
N79-15082

Key Words: Dynamic stability, Fluid-induced excitation, Supersonic aircraft, Aircraft, Shock excitation

The problem of dynamic stability is studied based on inviscid flow theory. The amplitude and frequency of the pitching oscillation are assumed small and a perturbation method employed. Systematic investigations of the closed form analytic formulae for the stability derivatives of oscillating wedges, flat plates, delta wings (with attached shock waves or detached shock waves) lead to conclusions given in the report.

79-1628
The Development of a Parametric Method of Measuring Fin Fatigue Loads Based on Flight Measurements on a Lightning Mk T5
A. Burns, J.P. Thompson, and E.W. Wells
Structures Dept., Royal Aircraft Establishment, Farnborough, UK, Rept. No. ARC-R/M-3824; BR64-876, 58 pp (1978)
N79-15956

Key Words: Aircraft, Flight tests, Fatigue tests, Parametric response

Load measurement is discussed in which load is deduced from a statistical correlation with an appropriate combina-

tion of aircraft motion variables and control surface angles. A full-scale flight experiment on a Lightning Mk T5 is described aimed at developing a parametric method for the measurement of fin fatigue loads under operational conditions. An empirical relationship was established between the fin root bending moment, as determined from a multi-strain gauge installation, and a combination of parameters. The parameters from which the combination is selected include translational and rotational accelerations, rates of rotation, rudder angle and angle of sideslip. The study covers the measurement of fin loads under a wide range of loading conditions.

79-1629

Nonlinear Parameter Identification and its Application to Transport Aircraft

T.J. Galbraith and T.J. Petersen

Boeing Commercial Airplane Co., Renton, WA, In: AGARD Dyn. Stability Parameters, Nov 1978, 20 pp

N79-15078

Key Words: Aircraft, Parameter identification technique, Computer programs

A nonlinear parameter identification computer program and results obtained from analyzing jet transport flight data characterized by nonlinear motion and parameters is described. The program is called NLAK for nonlinear aerodynamics and kinematics and is part of a system of computer programs for analyzing airplane dynamic response data. The flight data analyzed was low speed, below 150 knots. The analysis system is outlined and all interfaces with the NLAK program are described. The basic concepts and some of NLAK's formulation details are also described in relation to obtaining consistent estimation results, especially for the nonlinear problem.

79-1630

A Survey of Analytical and Experimental Techniques to Predict Aircraft Dynamic Characteristics at High Angles of Attack

A.M. Skow and A. Titiriga, Jr.

Aerosciences Research Dept., Northrop Corp., Hawthorne, CA, In: AGARD Dyn. Stability Parameters, Nov 1978, 37 pp

N79-15079

Key Words: Aircraft, Aerodynamic loads

A survey of some of the techniques that will aid the fighter aircraft designer in building good high angle-of-attack aerodynamic characteristics into the airframe is presented. Some of the more well known analytical and experimental methods and endeavors to highlight the contributions each method provides are summarized.

79-1631

Sensitivity of Aircraft Motion to Aerodynamic Cross-Coupling at High Angles of Attack

W.H. Curry and K.J. Orlik-Rueckemann

Sandia Labs., Albuquerque, NM, In: AGARD Dyn. Stability Parameters, Nov 1978, 18 pp

N79-15094

Key Words: Aircraft, Aerodynamic loads, Computerized simulation

The equation of motion was examined using a six-degree-of-freedom simulation on a hybrid computer. Both straight and turning flight conditions were included, and to simplify the problem, the equations were formulated for the constant-thrust, stick-fixed condition. The aerodynamic cross-coupling derivatives were considered both as constants and as locally linearized functions of angle of attack. The effects of varying certain derivatives from an assumed nominal set on the response of the aircraft to an initial perturbance are presented graphically.

79-1632

Prediction of Unsteady Aerodynamic Forces in High Frequency Oscillatory Flow

H. Foersching

Deutsche Forschungs- und Versuchsanstalt f. Luft- und Raumfahrt, Goettingen, West Germany, In: Von Karman Inst. for Fluid Dyn. Aerodyn. Inputs for Probl. in Aircraft Dyn., Vol. 2, 80 pp (1977)

N79-15915

Key Words: Aircraft, Aerodynamic loads

A review is made of current advances in the development of analytical methods and related computation techniques for the prediction of the motion-induced unsteady aerodynamic inputs for problems in high-frequency aircraft dynamics. The practical applicability and reliability of the various methods is demonstrated and some topics for further research work are indicated.

79-1633

Dynamics of Complex Structures-Analysis and Experiment: Damaged Aircraft Stabilators

J.H. Smith and W.L. Beason
Dept. of Civil Engrg., Texas Tech. Univ., Lubbock, TX, Rept. No. AFOSR-TR-78-1621, 88 pp (Nov 1978)
AD-A062 691/1GA

Key Words: Aircraft, Complex structures, Stabilizers (fluid dynamics), Stiffness, Natural frequencies, Damping, Computer programs

This report presents the results of an experimental and analytical program employed to determine the effect that damage to a horizontal stabilator has on structural characteristics such as stiffness, natural frequencies and damping. A simplified method of computing the change in the fundamental frequency as damage increases is also developed.

79-1634

Vibration Suppressing Trunk Fingers for Air Cushion Devices

D.J. Perez
Dept. of the Air Force, Washington, D.C., PAT-APPL-938 993/GA, 13 pp (Sept 1, 1978)

Key Words: Aircraft, Landing gear, Air cushion landing systems

The patent application relates to an aircraft air cushion takeoff and landing system with a flexible trunk section in the form of a large expandable tube, having multiple air exhaust holes in the bottom thereof, encircling the bottom of the fuselage, a group of flexible finger-like protrusions beneath the forward section of the trunk. The downwardly extending finger-like protrusions make intrusions make intermittent contact with the ground surface to suppress vertical vibrations in the trunk when the aircraft is hovering at ground level with the trunk inflated.

79-1635

A Computational Scheme for Structural Influence Coefficients of Certain Planar Wings

J.E. Moore, Jr. and M.A. Cutchins
Air Force Armament Lab., Eglin Air Force Base, FL, J. Aircraft, 16 (5), pp 315-319 (May 1979) 3 figs, 10 refs

Key Words: Aircraft wings, Influence coefficient matrix, Computer programs

The objective of this work was to reduce the amount of numerical computation work involved in obtaining structural influence coefficients, especially for special-purpose computer programs involving wings that have elastic axes that can be approximated by a series of straight line noncolinear segments. The need for repetitive runs, probably due to different mass arrangements, enhances the desirability of the technique.

79-1636

Airframe Aerodynamic Noise - Total Radiated Acoustic Power Approach

L.L. Shaw
Air Force Flight Dynamics Lab., Wright-Patterson AFB, OH, Rept. No. AFFDL-TR-78-141, 80 pp (Nov 1978)
AD-A062 861/0GA

Key Words: Aircraft noise, Airframes, Noise measurement

During flight the noise radiated by aircraft is emanating from two distinct types of sources. One source is the propulsion system and the other is the non-propulsion system noise, or airframe noise, associated with movement of the aircraft through the atmosphere. The purpose of this effort was to study the air-frame noise using a total radiated acoustic power approach. Methodology was developed to accurately calculate the total acoustic power by using measurements from an array of microphones during aircraft flyover. This methodology was applied to Schweizer 2-32 glider flyovers and it was found that for an aerodynamic configuration (no flaps, wheels, wheel wells, etc.) the total acoustic power can be obtained from one flyover measurement by assuming the directivity is nearly equal in all directions.

79-1637

Feasibility of Wing Shielding of the Airplane Interior from the Shock Noise Generated by Supersonic Tip Speed Propellers

J.H. Dittmar
NASA Lewis Research Ctr., Cleveland, OH, Rept. No.. NASA-TM-79042; E-9845, 25 pp (Dec 1978)
N79-15757

Key Words: Aircraft noise, Interior noise, Noise reduction

A high tip speed turboprop is being considered as a future energy conservative airplane. Supersonic blade sections could generate noise that is a cabin environment problem. The feasibility of using wing shielding to lessen the impact of this supersonic propeller noise was investigated. An analytical model is chosen which considers that shock waves are assoicated with the propeller tip flow and indicates how they would be prevented from impinging on the airplane fuselage. An example calculation is performed where a swept wing is used to shield the fuselage from significant portions of the propeller shock waves.

79-1638

Lifting Surface Approach to the Estimation of Gust Response of Finite Wings

H. Okubo, M. Kobayakawa, and H. Maeda

Univ. of Osaka Prefecture, Sakai, Japan, J. Aircraft, 16 (5), pp 309-314 (May 1979) 10 figs, 13 refs

Key Words: Aircraft wings, Wind-induced excitation, Fluid-induced excitation, Turbulence

Unsteady response of finite wings flying through turbulence is investigated using linearized lifting surface theory. The NLR method, extended to the unsteady case, is employed for the numerical calculation of the lift force arising from oscillatory gusts for a wide range of frequencies. An efficient numerical procedure is presented for the estimation of the response to random turbulence. This procedure uses the relation between the output power spectral density and the spanwise cross-spectrum of turbulence, defined in terms of the spanwise correlated frequency response function, which in turn is derived from the aerodynamic transfer matrix for the modified upwash field. The results computed by means of this method with a model of turbulence uniform in span, and with a model of isotropic turbulence, exhibit considerable differences.

79-1639

Aerodynamics

P. Swan

British Aircraft Corp. (Operating) Ltd., Bristol, UK, In: Von Karman Inst. for Fluid Dyn., RPV's - Aerodyn. and Related Topics, Vol. 1, 44 pp (1977) N79-15947

Key Words: Aircraft, Fluid-induced excitation, Aerodynamic loads

An item that was checked with some care was downwash on both tail-controlled RPV's and a canard design.

BRIDGES

(Also see No. 1505)

79-1640

Free Torsional Vibrations of Suspension Bridges

A.M. Abdel-Ghaffar

Dept. of Materials Engrg., Univ. of Illinois at Chicago Circle, Chicago, IL, ASCE J. Struc. Div., 105 (ST4), pp 767-788 (Apr 1979)

Key Words: Suspension bridges, Torsional vibration

A generalized theory of free torsional vibration for a wide class of suspension bridges with double lateral systems is developed, taking into account warping of the bridge deck cross section and the effect of torsional rigidity of the towers. The analysis is based on a linearized theory and on the use of the digital computer. A finite element approach is used to determine vibrational properties in torsion. Simplifying assumptions are made, and Hamilton's principle is used to derive the matrix equations of motion. The method is illustrated by numerical examples. The objective of the study is to clarify the torsional behavior of suspension bridges and to develop a method of determining a sufficient number of natural frequencies and mode shapes to enable an accurate practical analysis.

79-1641

Suspension Bridge Vibrations: Computed and Measured

P.G. Buckland, R. Hooley, B.D. Morgenstern, J.H. Rainer, and A.M. van Selst

Buckland and Taylor Ltd., Consulting Engrs., Vancouver, B.C., Canada, ASCE J. Struc. Div., 105 (ST5), pp 859-874 (May 1979)

Key Words: Suspension bridges, Vibration measurement

Measured frequencies of a suspension bridge were found to differ from those calculated by a wide margin. The discrepancies were found to be caused by sliding deck joints not sliding at small amplitudes, which affected the stiffness. When these and other minor effects were correctly modeled the agreement was excellent. Lateral-torsional coupled motion caused by a channel type cross-section was found to

influence the position of the center of rotation, which has an effect on the aerodynamic behavior. Measured values of structural damping are given, and a comparison is made between "approximate" and "exact" methods of computing natural frequencies and mode shapes.

79-1642
Dynamic Analysis of Curved Box Girder Bridges
D. Mukerjee and D.N. Trikha
Bengal Engrg. College, Howrah, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 471-476, 2 figs, 4 tables, 5 refs

Key Words: Bridges, Box beams, Natural frequencies, Mode shapes, Finite element technique

To study the dynamic behavior of twin cell concrete box girder bridges curved in plan, essential features of curved strip finite element formulation have been presented giving procedures for determining natural frequencies and the corresponding mode shapes. Dynamic response has been defined by "dynamic factors" for individual girders for a moving load occupying any position on the span.

79-1643
Selection of Critical Bridges for Retrofitting
A. Longinow, J.D. Cooper, and E. Bergmann
Illinois Inst. of Tech., Research Inst., Chicago, IL, ASCE, J. Technical Councils, 105 (TC1), pp 197-210 (Apr 1979)

Key Words: Bridges, Earthquake resistant structures

This narrative addresses itself to the identification of the criticality of the bridge in relation to the road, the road network, the community, and the national defense/security system. The criticality of the bridge is then compared to its ability in resisting the disaster and a need to retrofit (or not to retrofit) the bridge is established. The objective is to produce a procedure whereby a decision can be made as to which bridges in a given road network need to be retrofitted relative to a given earthquake.

79-1644
Parametric Study of Vibration of Highway Bridges Under System of Moving Load
B.C. Rajanna and N. Minirudrappa
Univ. Visvesvaraya College of Engrg., Bangalore Univ., Jnana Bharathi, Bangalore 560 056, India, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 477-483, 10 figs, 27 refs

Key Words: Bridges, Moving loads, Parametric response

The present study aims to evaluate the bridge deflection and stresses resulting due to the following parameters: speed of moving vehicle; the mass of the vehicle and beam mass; and the ratio of the weights of unsprung and sprung masses of the vehicle parts. The study has been made considering the two dimensional behavior of the highway bridge by treating the entire bridge as an orthogonal bridge grid consisting of longitudinal and cross beams.

79-1645
Influence of Soil Structure Interaction on the Dynamic Behaviour of Cable-Stayed Bridges
P. Krishna, A.D. Pandey, P. Nandakumaran, and S. Ahmed
Civil Engrg. Dept., Univ. of Roorkee, U.P., India, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 247-252, 3 figs, 1 table, 6 refs

Key Words: Interaction: soil-structure, Cables (ropes), Bridges, Seismic response

Cable-stayed bridges have been constructed in many countries and are becoming more popular among structural engineers. Soil structure interaction studies of such bridges for static load have been carried out but little effort has been made to study the influence of soil properties on their dynamic behavior. An attempt has been made here to study the effect of horizontal subgrade reaction on the dynamic behavior of a two span cable-stayed bridge. Various types of soil media have been considered, ranging from loose to very dense soil.

BUILDING
(Also see No. 1680)

79-1646
Light Weight Aggregate Concrete for Seismic Zones
N. Chitharanjan and A.R. Santhakumar
College of Engrg., Guindy, Madras, Symp. Earth-

quake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 305-310, 2 figs, 2 tables, 5 refs

Key Words: Buildings, Multistory buildings, Concrete, Seismic response

Sintered flyash, when used as Light Weight Aggregate in non-load bearing partitions reduces the dead load. This consequently reduces the seismic lateral load on which the quantity of steel is dependent. This paper conclusively shows that Light Weight Concrete using the above aggregates can be successfully made. The properties of concrete, using these aggregates, have been reported. The effect of static cyclic load on this material has been analyzed and an equation to calculate the stress at any strain level has been proposed.

79-1647

Experimental Evaluation of Aseismic Strengthening Methods of Brick Buildings

M. Qamaruddin, A.S. Arya, and B. Chandra
Dept. of Earthquake Engrg., Univ. of Roorkee, U.P., India, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 353-360, 3 figs, 1 table, 8 refs

Key Words: Buildings, Masonry, Seismic design, Model testing

The paper presents the results of experimental investigations carried out to study the behavior of brick buildings constructed with different aseismic arrangements under the action of shock loading. For this purpose model tests were conducted on eight differently constructed single-story brick structures. The tests were performed on the railway wagon shake table facility developed at the School of Research and Training in Earthquake Engineering, University of Roorkee, Roorkee.

79-1648

Investigation on Overturning of Aseismic Buildings

S.A. Petrovich
Moscow, USSR, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 277-282, 8 figs, 5 refs

Key Words: Buildings, Multistory buildings, Seismic response

During Nijgata earthquake (Japan 1964) multistory buildings of seismic resistance construction were overturned. This phenomenon was explained as a result of liquification of the saturated sand foundation. Detailed investigations performed show that the liquification effect of the foundation influences the irregular displacement of a foundation structure but cannot cause complete overturning of the building. By considering seismometric data and using general methods of wave mechanics it is possible to determine the vibrations of the building caused by the traveling elastic and plastic waves.

79-1649

Seismic Loads and Soil Conditions

K.V. Egupov
Odessa Engrg. Inst. of Merchant Marine, USSR, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 301-304, 1 fig

Key Words: Buildings, Seismic design

This report is concerned with the design methods of buildings as spatial systems accounting unevenness of oscillations field of soil and the differentiation of the seismicity and dynamicity coefficients by types of oscillations. The cause of appearance of torsional oscillations are analyzed in those cases, when distribution of stiffness characteristics in buildings are symmetrical.

79-1650

Impact Excited Vibration Studies in a Building

B.S. Ram and R.K. Bhandari
Central Building Research Inst., Roorkee, India, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 345-352, 6 figs, 6 tables, 7 refs

Key Words: Buildings, Impact response (mechanical)

Impact excitation of a building, due to a falling weight inside it, was monitored. The energy of impact was varied from 650 to 5000 kgm and the response data were utilized to forecast the impact of vibrations generated by dropping of a 600 kg almirah through a height of 5m; obtain comparison with provisions of IS: 6922-1973; and examine the various correlations available for computing the velocity amplitude of vibration vis-a-vis the safety criteria.

79-1651

Intermodal Soil Damping in Buildings

M.G. Joseph and R. Radhakrishnan
Central Public Works Dept., Room No. 203, A Wing, Nirman Bhawan, New Delhi, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 283-288, 5 figs, 4 refs

Key Words: Buildings, Interaction: soil-structure, Damping values

Damping idealization in the sway mode of vibrations is very important in seismic analysis of buildings with soil interaction, as the sway mode introduces large damping in some of the building modes and the response is very sensitive to this. One of the methods to account for this is to adopt large values of coefficient of critical damping in the sway mode, in an empirical and adhoc manner. In the present work intermodal soil damping values are determined in a rigorous manner and utilized in the analysis.

FOUNDATIONS AND EARTH

(Also see Nos. 1507, 1508, 1534, 1544)

79-1652

Effect of Parameters Influencing the Coefficient of Elastic Uniform Compression of Soils

P. Nandakumaran and R.K. Sharma
Dept. of Earthquake Engrg., Univ. of Roorkee, U.P., India, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 129-136, 9 figs, 9 refs

Key Words: Machine foundations, Dynamic tests, Compressive strength

The coefficient of elastic uniform compression C_u is an important parameter in the design of the machine foundations. The various factors likely to affect the value of C_u are the type of soil, size and shape of foundation, stress intensity and the nature of loading. None of the theories available account for the effect of water table, static stress below the foundation and the total stress (static & dynamic) on the coefficient of elastic uniform compression. This paper is an attempt in this direction and describes an experimental study of this problem. 252 tests were conducted in the laboratory under controlled conditions. The various parameters considered were the size of loaded area, the dynamic stress, the static stress, and the depth of water table from the base of the plate.

79-1653

Alterations to a Machine Foundation - A Case Study

P. Srinivasulu, C.V. Vaidyanathan, and N. Lakshmanan
Structural Engrg. Research Ctr., Madras-20, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 237-242, 3 figs, 2 tables, 5 refs

Key Words: Machine foundations, Impact response (mechanical), Vibration control

The paper presents a case study which involves a structural modification to an existing machine foundation. The machine in question is a jolter which is an impact causing machine located in a foundry forge plant. The structural modification was needed to enable the existing foundation to support another machine of a similar type but of a larger capacity.

79-1654

Natural Frequencies of Embedded Foundations in Horizontal Vibrations

P. Nandakumaran, V.K. Puri, and P.S. Singh
Dept. of Earthquake Engrg., Univ. of Roorkee, U.P., India, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 187-192, 6 figs, 8 refs

Key Words: Machine foundations, Interaction: soil-foundation, Natural frequencies, Periodic excitation

The paper describes a simple analytical approach for predicting natural frequencies of embedded foundations subjected to simultaneous rocking and sliding. The method is basically an extension of Barkan's approach for surface footing. The predicted relative increase in natural frequency as a result of embedment in relation to the natural frequency of the footing resting on the surface, computed on the basis of suggested approach has been found to show good agreement with experimental data.

79-1655

Dynamic Studies of 200 MW Turbo-Generator Foundation

A.V. Wedpathak, P.K. Bhandwalkar, V.K. Pandit, and S.K. Guha
Central Water and Power Res. Station, Khadakwasla, Pune, India, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 181-186, 5 figs, 3 tables, 9 refs

AD-A074 320 NAVAL RESEARCH LAB WASHINGTON DC SHOCK AND VIBRATION--ETC F/G 20/11
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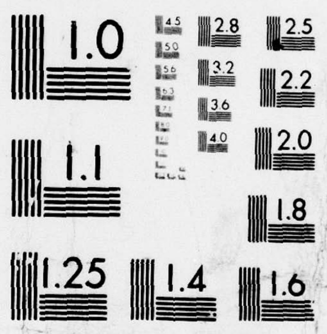

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Key Words: Machine foundations, Turbomachinery, Natural frequencies, Damping coefficients

Dynamic studies were conducted for frame type concrete foundation of 200 MW Turbo-Generator set for estimating its natural frequencies in various modes initially by theoretical dynamic analysis, model studies and finally by prototype experiments. The results of natural frequencies obtained from these studies have been found to be in reasonably good agreement.

79-1656

Analytical Solutions for Coupled Vibrations

M.S. Subrahmanyam and H.R. Sreekantiah

Dept. of Civil Engrg., Indian Inst. of Tech., Madras, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 401-406, 2 figs, 2 tables, 7 refs

Key Words: Coupled response, Machine foundations

For the successful design of a machine foundation subjected to coupled modes of rocking and sliding vibrations one has to predict properly the peak amplitudes and resonant frequencies in rocking and sliding motion. In this paper, analytical solutions to predict the rocking component of the coupled motion, for four cases of annular ring-uniform contact pressure distributions and for higher order parabolic contact pressure distributions have been presented. The solutions have been presented in the form of curves for ready use. The sliding component of the coupled motion has been predicted by making use of the existing analytical solutions for horizontal vibrations.

79-1657

Frame Foundations for High Speed Centrifugal Compressors for NFL Fertilizer Projects

J.K. Bagchi, J. Raman, and K.N. Sinha

Engineers India Limited, New Delhi, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 231-236, 5 figs, 2 tables, 4 refs

Key Words: Machine foundations, Compressors

The analysis of high speed centrifugal compressors carried out for a Fertilizer factory by using three different models have been discussed. The machine data as well as results of the dynamic analysis of these foundations have been presented.

79-1658

Rotational Vibrations of Embedded Foundations

K.S. Sankaran, N.R. Krishnaswamy, and P.G.B. Nair

Civil Engrg. Dept., I.I.T., Madras, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 219-224, 3 figs, 1 table, 9 refs

Key Words: Machine foundations, Torsional vibration, Mathematical models, Interaction: structure-foundation

In this paper, an attempt has been made to develop a single-degree-of-freedom analogue model, the parameters of which are expressed in terms of the results of the half-space theory and an additional parameter to account for the effect of embedment. The suggested parameter takes into consideration the relevant physical characteristics of the interface between the foundation walls and the surrounding soil as well as the foundation base and the soil beneath. A closed-form solution has been obtained and the same is presented herein. The analytical solutions are presented in non-dimensional form as useful graphs. The theoretically predicted values of resonant frequency and maximum amplitude of rotation are compared with the experimental data and found to be satisfactory.

79-1659

Prediction of Dynamic Response of Foundations

J. Raman and A. Sridharan

Engineers India Limited, New Delhi, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 199-204, 4 figs, 13 refs

Key Words: Machine foundations, Interaction: soil-foundation, Model testing

For foundations subjected to steady state vibration of low amplitude, the behavior soil medium is assumed to be elastic. Most of the theories of prediction of the dynamic response of foundations are based on the elastic approach. This study discusses the applicability of the elastic theories for the prediction of the dynamic response of foundations.

79-1660

Embedment Effect on Dynamic Response of Footings

G. Ranjan, S. Kumar, S. Saran, and R.C. Vijayvargiya

Univ. of Roorkee, Roorkee, India, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 193-198, 4 figs, 2 tables, 13 refs

Key Words: Footings, Dynamic response, Interaction: soil-foundation

The analysis of vibrating footing may be carried out either by theory of elasticity or the theory of spring-mass dash pot systems. The dynamic elastic constants of soils are necessary for finding out the stiffness of soil springs required in the analysis. The paper deals with the influence of embedment on dynamic response of footings. The study is carried out through field tests on two size blocks. The blocks are subjected to vertical resonance tests. Cyclic plate/block tests have also been carried out.

79-1661

Dynamic Behaviour of Vibro-Piles

P. Srinivasulu, N. Lakshmanan, and T.S. Thandavamoorthy

Structural Engrg. Research Centre, Madras, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 213-218, 2 figs, 1 table, 7 refs

Key Words: Pile driving, Vibratory techniques, Interaction: soil-structure, Resonant frequencies, Longitudinal vibration

Vibropiles are effectively used in pile driving operations. This paper presents a dynamic analysis leading to the evaluation of resonant frequency of the pile under longitudinal vibration, and the amplitude realized at the tip of the pile at resonance for various degrees of embedment. The numerical results computed are found to be in close agreement with those reported by previous investigators. The proposed analysis accounts for most of the parameters involved. These include the inertia, stiffness, and damping offered by the soil surrounding the pile at different stages of embedment.

79-1662

Dynamic Response of Structures on Piles - A Simplified Model

A.R. Chandrasekaran, M.K. Gupta, and P. Kumar

Dept. of Earthquake Engrg., Univ. of Roorkee, U.P., India, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 243-246, 8 figs, 4 refs

Key Words: Pile foundations, Interaction: structure-foundation, Mathematical models, Two-degree-of-freedom-systems, Seismic response

The analysis of structures, supported on flexible pile foundations and subjected to dynamic loads, involves the problem of interaction between soil pile and superstructure systems. In the theoretical work reported herein, the complex system has been assumed to be represented by an equivalent two degree of freedom system. Experimental studies have also been conducted by mounting a single degree mass-spring system on an aluminium pile head embedded in sand. The response of the system has been obtained by giving it sinusoidal vibrations. The above model has been theoretically analyzed, by using experimentally evaluated constants associated with the model. The results obtained by experimental observations and those obtained by theoretical analysis have compared well.

79-1663

Dynamic Stiffness for Rectangular Rigid Foundations on a Semi-Infinite Elastic Medium

Y. Kitamura and S. Sakurai

Dept. of Civil Engrg., Kobe Univ., Kobe 657, Japan, Intl. J. Numer. Anal. Methods Geomech., 3 (2), pp 159-171 (Apr 1979) 11 figs, 10 refs

Key Words: Rigid foundations, Harmonic excitation, Numerical analysis

The present paper deals with the dynamic steady-state force-displacement relationships (complex stiffness) for rectangular rigid foundations resting on a semi-infinite medium, consisting of homogeneous, isotropic, linear elastic materials. The foundations are considered to be excited under harmonic vertical and rocking vibrations. This gives mixed boundary value problems which cannot be easily solved by analytical approaches. Therefore, a numerical method is proposed here. The method is based on quite simple equations, and is straightforward in computation, compared with other methods. The results obtained by the proposed method are compared with those of other methods to evaluate the accuracy of the results. The effects of length/width ratio and the area of the contact plane of the foundations are also discussed.

79-1664

Dynamic Response of Surface and Embedded Disk Foundations for SH, SV, P and Rayleigh Wave Excitation

D. Ray, A. Zebarjadian, and J.O. Dizon

Urs/John A. Blume & Assoc., Engineers, San Francisco, CA 94105, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 205-212, 10 figs, 10 refs

Key Words: Rigid foundations, Interaction: soil-foundation, Wave diffraction, Seismic excitation

A class of important soil-structure interaction phenomenon, namely, wave scattering, is introduced and accounted for by a simple yet realistic and inexpensive concept of filtering. The dynamic responses of a rigid massless surface and embedded disk foundation welded to an elastic half-space, and subjected to generally obliquely incident SH, P and SV waves, and horizontally propagating Rayleigh waves, are investigated.

79-1665

Effect of Foundation Vibrations on Nearby Structures

G. Gazetas

National Technical Univ. of Athens, Greece, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 253-258, 6 figs, 16 refs

Key Words: Foundations, Interaction: soil-structure, Coupled response, Seismic response

The paper presents a semi-analytical method for estimating the response of two massive, rigid, infinitely long foundations attached to the surface of a linearly hysteretic layered half-space when either one is subjected to harmonic forces. Results are presented showing the importance of foundation mass and soil layer depth for the response of two identical structures placed on a single soil layer on rock. Limitations of this 2D method are discussed and qualitative corrective measures are proposed.

79-1666

Plane-Strain Soil-Structure Interaction for Seismic Response

G. Gazetas and J.M. Roesset

National Technical Univ. of Athens, Greece, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 259-264, 3 figs, 18 refs

Key Words: Foundations, Interaction: soil-structure, Seismic response

The general characteristics of plane strain solutions for the dynamic stiffness of foundations including the effects of layer depth and underlying rock flexibility, are discussed and compared to those of truly three dimensional formulations. Because of some important differences between the behavior of strip footings and circular or square foundations it is recommended that some initial, preliminary analyses be conducted before embarking into expensive two dimensional computer runs. A simplified impedance approach is suggested to obtain estimates of the errors involved.

79-1667

Stability Analysis and Model Tests of Dam Foundations Subjected to Earthquake Loads

L.S. Srivastava

Dept. of Earthquake Engrg., Univ. of Roorkee, U.P., India, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 175-179, 4 figs

Key Words: Foundations, Dams, Seismic response, Model testing

The model test and three dimensional stability analysis carried out for evaluation of stability of dam foundations at dam sites A and B helped in identification of the critical wedges and their mode of movement for evaluation of factor of safety against earthquake forces for the particular design horizontal seismic coefficient. The methods also help in providing data for adoption of suitable remedial measures and evaluation of the efficacy of the treatment required for the stability of the foundation.

79-1668

Hydrodynamic Pressure on an Accelerating Dam and Criteria for Cavitation

A.T. Chwang

Div. of Engrg. and Appl. Science, California Inst. of Tech., Pasadena, CA, J. Engr. Math., 13 (2), pp 143-152 (Apr 1979) 4 figs, 6 refs

Key Words: Dams, Seismic response

The effect of finite reservoir on the hydrodynamic pressure due to horizontal as well as vertical ground excitations has been studied. A simple criterion has been presented in this paper which would enable dam engineers to determine whether a given earthquake could cause cavitation at the dam-water interface or not.

79-1669

Soil Dams' Stability Under Seismic Force

V.I. Nikolau

Odessa Engrg. Inst. of Merchant Marine 34, Mechnikov St., Odessa, USSR, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 171-174, 2 figs, 3 refs

Key Words: Dams, Seismic response

The stability of the soil dams with any angle of seismic force is described. The criterion of the stability is established by means of limiting the zone of the plastic balance in the soil dams with free chosen angle of the slope provided the dam is the infinite wedge with consideration for the gravity. The stress-strained condition of the dam is determined according to the linearly-deformed medium model, based on the volume moment stresses or moment per unit volume. The condition of the plastic balance is obtained on the base of the same model.

79-1670

Economics of Seismic Stability of Earth Dams

M.V. Bhave

Warna Dam Div., Kolhapur, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 163-170, 3 figs, 4 tables, 4 refs

Key Words: Dams, Seismic design

In general there are two methods available for the seismic design of earthen dams: the pseudostatic method and the dynamic displacement method.

79-1671

Analytical Studies of Dynamic Pore Pressures

S.M. Goel

Dept. of Irrigation and Agricultural Machinery Engrg., College of Engrg., Univ. of Mosul, Iraq, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 125-128, 2 figs, 6 refs

Key Words: Dams, Seismic design, Soils, Compressive strength

The problem of development of excess pore pressure during earthquakes in porous, fully saturated and square body has been studied analytically under comprehensive initial and boundary conditions. The effect of compressibilities of fluid and structure has been included.

79-1672

Seismic Analysis of Slopes in the Northeast U.S.A.

D. Athanasiou-Grivas

Dept. of Civil Engrg., Rensselaer Polytechnic Inst., Troy, NY, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 157-162, 10 figs, 1 table, 4 refs

Key Words: Earth structures, Seismic response

The two objectives of the present study are: to describe some seismic characteristics of the Northeastern U.S. that are of geotechnical engineering interest, and to examine their influence on the safety of earth slopes located in the region. The probability distribution of the earthquake magnitude is obtained with the aid of a log-linear magnitude-recurrence relation and its dependence on the numerical values of the regional parameters is investigated. An upper and lower bound for the magnitude have been considered on the basis of the available data. The statistical values and probability distribution of the maximum ground acceleration are also determined. An "error term" is introduced in an attempt to improve the correspondence between observed and computed values. Finally, in a case study, the dependence is examined of the safety of a soil slope on the choice of the attenuation relation, the numerical values of regional parameters, and the distance between the earthquake source and the site of the slope.

HELICOPTERS

79-1673

Simulation Correlation, and Analysis of the Structural Response of a CH-47A to Crash Impact

Y.V. BadriNath

Boeing Vertol Co., Philadelphia, PA, Rept. No. D210-11354-1, USARTL-TR-78-24, 312 pp (Aug 1978)

AD-A062 643/2GA

Key Words: Helicopters, Crash research (aircraft), Computer programs

The purpose of this effort was to model the dynamic response of the CH-47A helicopter to a crash impact using program KRASH and to correlate the results with data from a CH-47A crash impact test. An improved version of KRASH developed at Boeing Vertol was used for this purpose. This report contains details of the development of a CH-47A KRASH structural model, the pretest predictions, and the description of the CH-47A crash impact test data. Post-test improvements to the structural model to improve correlation

with test data are discussed. Problems related to the computer program which arose during the course of the simulation and correlation efforts are discussed in detail.

79-1674

Crashworthiness Versus Cost: A Study of Army Rotary Wing Aircraft Accidents in Period January 70 through December 71

J.L. Haley and J.E. Hicks
Army Aeromedical Res. Lab., Fort Rucker, AL, 32 pp (Dec 1971)
AD-A062 722/4GA

Key Words: Helicopters, Crashworthiness, Crash research (aircraft)

This paper discusses the economic benefits of providing improvements in crashworthiness within future Army aircraft. The crashworthiness improvements considered are those of Military Standard 1290, Light Fixed- and Rotary-Wing Aircraft Crashworthiness. The benefits in reduced personnel losses and airframe damage were studied using 299 severe accidents occurring to Army rotary wing aircraft during 1970 and 1971. These accidents were analyzed in detail under a joint USAAAVS/USAARL study effort. The crashworthiness benefits are applied to the Utility Tactical Transport Aircraft System (UTTAS) and projected on a per-flight-hour basis over its lifetime. The total costs of providing these crashworthiness improvements are estimated using a simple model based on aircraft weight. These costs include both initial acquisition costs and recurring maintenance and operating costs. The benefits resulting from the increased level of crashworthiness are then compared with the costs of providing these improvements in UTTAS aircraft.

79-1675

Unsteady Pressure Measurement on Rotor Blade Tips with Incidence

H. Triebstein
Deutsche Forschungs- und Versuchsanstalt f. Luft- und Raumfahrt E.V., Institut f. Aeroelastik, Gottingen, West Germany, AIAA J., 17 (5), pp 514-518 (May 1979) 14 figs, 3 refs

Key Words: Rotary wings, Wind tunnel tests

Measurements of pressure distributions on a harmonically oscillating rotor blade wing in low subsonic speed are reported. The measurements were carried out in the 3 x 3 m subsonic wind tunnel of the DFVLR in Gottingen. Pressures were measured at five sections of the wing in such a way that the three-dimensionality of the pressure distribution could be well observed. Comparisons with theoretical and experimental results were made. The analytic predictions were found to agree well with the measured data. A brief description of the test facilities is also presented.

ISOLATION

79-1676

Controlling Vibration and Noise From Packaged HVAC Equipment

R.S. Jones
Bolt Beranek and Newman, Inc., Cambridge, MA, Plant Engrg., 33 (10), pp 131-135 (May 17, 1979) 8 figs

Key Words: Machinery noise, Machinery vibration, Vibration isolation, Air conditioning equipment

Basic considerations for the control of noise and vibration of heating, ventilating, and air conditioning equipment are discussed. Suggestions for selecting a vibration-isolation system that will adequately separate the driving frequencies of the equipment being isolated from the natural frequencies of the building structure are given.

79-1677

Servovalve-Controlled Pneumatic Suspensions

E. Esmailzadeh
Arya-Mehr Univ. of Tech., Tehran, Iran, J. Mech. Engr. Sci., 21 (1), pp 7-18 (Feb 1979) 13 figs, 21 refs

Key Words: Suspension systems (vehicles), Pneumatic isolators

A linear analytical model of a ground-vehicle suspension system employing a pneumatic isolator and a three-way servovalve is developed. Damping is provided by connecting the pneumatic spring to a constant-volume surge tank through capillary resistances. Non-dimensional dynamic equations for the valve-controlled, self-damped, pneumatic isolator are derived and the effects of various feedback and feedforward controls on the performance of the closed-loop system are pointed out. Experiments are conducted to verify the validity of the assumptions made in deriving the absolute and relative displacement transmissibilities and the vehicle model is simulated on an analog computer.

79-1678

Vibration Isolation in the Presence of Coulomb Friction

A. Schlesinger

School of Engrg., Univ. of Bath, Claverton Down, Bath BA2 7AY, UK, J. Sound Vib., 63 (2), pp 213-224 (Mar 22, 1979) 5 figs, 7 refs

Key Words: Coulomb friction, Vibration isolation

Transmissibility curves for a Coulomb-damped flexible mounting are presented for both rigidly and elastically coupled damping. The closed solutions easily obtainable for the slipping and sticking phases of the motion are used in the method, and no conceptual approximation is involved. The transmissibility curves are compared with previously published approximations based on linearization of the damping.

79-1679

A State Space Method for Optimal Design of Vibration Isolators

M.H. Hsiao, E.J. Haug, Jr., and J.S. Arora

Div. of Materials Engrg., College of Engrg., The Univ. of Iowa, Iowa City, IA 55242, J. Mech. Des., Trans. ASME, 101 (2), pp 309-314 (Apr 1979) 2 figs, 1 table, 16 refs

Key Words: Vibration isolators, Optimum design

A state space method of optimal design of dynamic systems subjected to transient loads is developed and applied. A state space approach is employed which develops the sensitivity analysis and optimization algorithm in continuous state space, resorting to discretization only for efficient numerical integration of differential equations. A numerical comparison of the state space and conventional nonlinear programming methods is carried out for two test problems, in which the state space method requires only one-tenth the computing time reported for the nonlinear programming approach.

79-1680

Buildings on Gravitational Seismoisolation System in Sevastopol

V.V. Nazin

Constructional Institute "Promstrojproekt" Pyatigorsk, USSR, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 365-368, 5 figs

Key Words: Seismic isolation, Buildings, Seismic design

The experimental construction carried out in Sevastopol indicates that from the technological point of view the erection of buildings with gravitational seismoisolation systems on a mass scale is quite possible.

79-1681

Isolator Parameters for Earthquake Response Reduction

A.S. Arya, R. Prakash, and R. Gopal

U.P. State Electricity Board, Lucknow, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 361-364, 5 figs, 1 ref

Key Words: Seismic isolation, Mathematical models

For an appropriate design of an earthquake isolator device for a structure, the significant parameters of the isolator, viz., mass, stiffness and damping are to be suitably related to the vibration characteristics of the structure being isolated as well as to the probable ground motion. The aim of this study is to investigate the nature of this relationship. The structure is represented by a single degree of freedom system and is assumed to be mounted on another single degree system representing the isolator. Thus the structure-isolator system is idealized as a two degree system. The elastic response of this system to the N-S component of El Centro Earthquake of 1940 is determined in terms of ratios of the stiffness, damping and the mass of the structure to those of the isolator.

MECHANICAL

79-1682

Topological Reaction Force Analysis

J.R. Milner and D.A. Smith

Desktop Computer Div., Hewlett-Packard, Loveland, CO, J. Mech. Des., Trans. ASME, 101 (2), pp 192-198 (Apr 1979) 19 figs, 16 refs

Key Words: Mechanical systems, Graphic analysis

A method of using directed linear graphs for the determination of reaction forces in dynamic mechanical systems is developed. The method is compatible with other more classical techniques for calculating reaction forces and results in a more efficient computational approach than alternative methods. Example problems are discussed and analyzed using these topological techniques.

79-1683
Predicting Acoustical Noise Generation in Complex Mechanical Systems
N.D. Perreira and S. Dubowsky
Dept. of Mech. Engrg., Univ. of Texas at Austin, TX, J. Mech. Des., Trans. ASME, 101 (2), pp 199-209 (Apr 1979) 12 figs, 8 tables, 24 refs

Key Words: Mechanical systems, Noise generation, Design techniques

A fundamental study of noise generation in complex mechanical systems is undertaken. The objective of the study is the development of design guidelines for the prediction of mechanical system noise levels. Recently developed dynamical procedures are used to obtain the motions of linked mechanical systems with elastic elements and connection clearances. An analytical procedure for modeling the acoustical noise generated by complex mechanical systems is applied to a typical linked system, a four-bar mechanism. The far field acoustic pressure distribution is calculated. To aid the designer in producing quieter systems, acoustic design functions are developed.

79-1684
Analysis and Simulation of Planar Mechanism Systems Using Bond Graphs
D. Karnopp and D. Margolis
Dept. of Mech. Engrg., Univ. of California, Davis, CA, J. Mech. Des., Trans. ASME, 101 (2), pp 187-191 (Apr 1979) 9 figs, 5 refs

Key Words: Mechanisms, Plane mechanisms, Bond graph technique

A method is presented for incorporating planar mechanisms into dynamic system models using bond graphs. Through the use of stiff coupling springs at the mechanism joints, the nonlinear geometrical relationships are uniformly and simply described by displacement modulated transformers and the system state equations can be written with no algebraic complications.

PUMPS, TURBINES, FANS, COMPRESSORS

79-1685
The Dynamic Behavior of Closed-Cycle Gas Turbines
G. Krey
Gutehoffnungshütte Sterkrade AG, Oberhausen, West Germany, In: Von Karman Inst. for Fluid Dyn. Closed Cycle Gas Turbines, Vol. 2, 30 pp (1977) N79-16266

Key Words: Gas turbines, Nuclear reactor components

The entry of the closed-cycle gas turbine into the range of high unit capacities and the intended use of nuclear power as a source of energy have led to increased requirements in respect of the accuracy and reliability of layout and design. There resulted the necessity to develop methods allowing advance calculation of the dynamic behavior of such plants. Knowledge of this behavior is necessary to arrive at a better and safer design of the circuit components and to allow safety and control equipment which meets the specific operating requirements to be designed. Such a method, which was developed on the basis of measuring results, is the subject of this work.

79-1686
Structure-Borne Pump Noise Quieted
Product Engr. (NY), 50 (5), pp 55-57 (May 1979) 6 figs

Key Words: Agricultural machinery, Ground vehicles, Pumps, Noise reduction, Design techniques

Hydrostatic drive systems and their variable-displacement pumps have been singled out as prime targets in the reduction of noise of agricultural machinery. Some of the noise reduction techniques are described.

79-1687
Effects of Inflow Distortion Profiles on Fan Tone Noise Calculated Using a 3-D Theory
H. Kobayashi and J.F. Groeneweg
NASA Lewis Research Ctr., Cleveland, OH, Rept. No. NASA-TM-79082; E-9904, 18 pp (1979) N79-16647

Key Words: Fans, Noise generation

Calculations of the fan tone acoustic power and modal structure generated by complex distortions in axial inflow velocity are presented. The model used treats the motor as a rotating three-dimensional cascade and calculates the acoustic field from the distortion-produced dipole distribution on the blades including noncompact source effects. Radial and

circumferential distortion shapes are synthesized from Fourier-Bessel components representing individual distortion modes. The relation between individual distortion modes and the generated acoustic modes is examined for particular distortion cases. Comparisons between theoretical and experimental results for distortions produced by wakes from upstream radial rods show that the analysis is a good predictor of acoustic power dependence on disturbance strength.

REACTORS

(Also see No. 1601)

79-1688

Size Effect in Damping Caused by Water Submersion

R.G. Dong
Lawrence Livermore Lab., Univ. of California, Livermore, CA, ASCE J. Struc. Div., 105 (ST5), pp 847-857 (May 1979)

Key Words: Nuclear power plants, Submerged structures, Viscous damping

In this paper, the added damping contribution that results from the viscosity of water and the dependence of the contribution on structural size are examined. Other factors considered are the applicable range of viscous damping with respect to displacement amplitude and, as far as damping is concerned, how far must neighboring members be from each other to respond as if in open water. An expression is derived for relating the damping value to structural size. Estimated added-damping values for representative fuel elements, fuel bundles, and main stream-pressure-relief-valve lines that are based on our derived expression for added damping are given.

79-1689

Dynamics of Component-Support Impact: An Elastic Analysis

E.C. Ting, S.S. Chen, and M.W. Wambsganss
School of Civil Engrg., Purdue Univ., West Lafayette, IN 47907, Nucl. Engr. Des., 52 (2), pp 235-244 (Apr 1979) 13 figs, 15 refs

Key Words: Nuclear reactor components, Fluid-induced excitation, Supports

As a part of the effort to correlate the flow excitation to the rate of component wear, the present paper studies a simple analytical model for the further understanding of the fundamental mechanism of component-support interaction. The usual modal expansion approach was adopted. Static Hertz type of contact was assumed for the component-support impact. The analysis was restricted to a fixed-fixed beam with a central baffle support subjected to free vibrations and damping effects were suppressed. Thus both the beam property and the contact action were assumed to be elastic. Numerical results of the study demonstrate a favorable correlation with the results of the experiments.

ROAD

79-1690

Dynamic Response of Pavements

P.D. Marathe and S.K. Khanna
Dept. of Civil Engrg., Univ. of Roorkee, U.P., India, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 449-454, 2 figs, 2 tables, 10 refs

Key Words: Pavements, Damping coefficients, Mass coefficients

In the first part of the paper, transfer functions of a pavement system have been obtained using dynamic models, consisting of spring-mass dashpot. In the second part, experimental techniques to determine transfer functions using observed input-output with impulsive forces have been briefly described. The application of time dependent transfer functions for predicting the dynamic response have also been indicated.

79-1691

Moving Loads in Structures by Finite Elements

F.V. Filho and H.J.C. Barbosa
Civil Engrg. Program, Coppe/Federal Univ. of Rio De Janeiro, Brazil, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 383-388, 2 figs, 1 table, 9 refs

Key Words: Moving loads, Mathematical models, Interaction: vehicle-structure, Finite element technique

A general formulation for the finite element analysis of the response of structures under moving loads is presented. An idealized vehicle constituted by an unsprung mass and a sprung mass with a suspension is used. The equations of

motion of the structural system are formulated from the stiffness, mass, damping and load matrices which are derived with the use of the interpolation functions of the finite element method. Consistent mass and load matrices are used. The damping matrices considered are of the Rayleigh type. Geometrically nonlinear structures are also considered and the dynamic response is obtained using step-by-step integration methods. Results in the form of impact factors for displacements are given and the influence of the various parameters such as velocity and acceleration of the moving load, mass of the load/mass of the structure, upon the structural response is displayed in these results.

ROTORS

(Also see No. 1546)

79-1692

Impedance Measurements on a Spinning Model Helicopter Rotor

R. Cansdale and D.R. Gaukroger

Structures Dept., Royal Aircraft Establishment, Farnborough, UK, Rept. No. ARC-CP-1389, 48 pp (1978)

N79-15955

Key Words: Rotors, Helicopter rotors, Mechanical impedance, Measurement techniques

The technique for measuring rotor impedances at the shaft of a model rotor is further developed. Values of impedance are presented for a four-blade rotor of semi-rigid design operating at zero lift, zero advance ratio, and a range of rotational speeds. The problems of interpreting and applying rotor impedances are discussed.

SHIP

79-1693

Hydrodynamic Behaviour of Rishikesh Undersluices Gates

J. Mohan, S.S. Tiagi, and M.K. Singhal

U.P. Irrigation Research Inst., Roorkee, India, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 443-448, 5 figs, 4 refs

Key Words: Hydraulic systems, Sluice gates, Model testing

Hydraulic behavior and forces caused by unbalanced water pressure above and below the gate cannot be assessed theoretically. In the present paper studies in respect of hydrodynamic behavior of undersluices gates of Rishikesh barrage conducted on a hydraulic model have been described. Different shapes of hood profile for the lower tier gates were tested.

SPACECRAFT

79-1694

Study of Multidegree of Freedom Systems for Vibrating Testing of Future Large Space Objects

Schildt, Schmid, Seifferth, and Merklinghaus

Hauptabt. Festigkeit, Konstruktion und Werkstoffe, Industrieanlagen-Betriebsgesellschaft m.b.H., Ottobrunn, West Germany, Rept. No. IABG-B-TF-768; ESA-CR(P)-1132, 237 pp (1978)

N79-16030

Key Words: Spacecraft, Test facilities, Vibration tests

Techniques are discussed that may be applied to equipping six-degree-of-freedom vibration test facilities with hydraulic cylinders. A facility is operating that is capable of moving in all degrees of freedom simultaneously, but was designed to use seismic signals in its tests and, consequently, has a relatively small usable frequency range. All available information seemed to indicate that it is quite possible to construct a test facility that would meet all requirements of frequencies of up to more than 200 Hz. The servovalves, including those with the required flow rates, are available on the market.

79-1695

Presentation of Stability Derivatives in Missile Aerodynamics and Theoretical Methods for their Prediction

C.P. Schneider

Messerschmitt-Boelkow-Blohm G.m.b.H., Munich, West Germany, In: AGARD Dyn. Stability Parameters, Nov 1978, 31 pp

N79-15080

Key Words: Missiles, Aerodynamics, Stability

Analytical procedures are indicated for the determination of pitching derivatives and coefficient essentially of arbitrary

planform wings, of bodies of revolution, and of combinations in the linear and nonlinear angle-of-attack range in subsonic and supersonic flow. A frame of classification of theory for missile design in particular is prepared due to the abundance of unsteady flow problems. The methods for the prediction of pitching derivatives and for solving stability problems arising with longitudinal acceleration of missile are described. Results indicate the importance of derivatives with respect of missile stability.

79-1696
A Procedure Obtaining Stiffnesses and Masses of a Structure from Vibration Modes and Substructure Static Test Data
H.H. Edighoffer
General Electric Co., Philadelphia, PA, Rept. No. NASA-CR-158984, 59 pp (Jan 1979)
N79-16301

Key Words: Launch vehicles, Component mode synthesis, Stiffness coefficients, Mass coefficients

A component mode desynthesis procedure is developed for determining the unknown vibration characteristics of a structural component (i.e., a launch vehicle) given the vibration characteristics of a structural system composed of that component combined with a known one (i.e., a payload). At least one component static test has to be performed. These data are used in conjunction with the system measured frequencies and mode shapes to obtain the vibration characteristics of each component. The flight dynamics of an empty launch vehicle can be determined from measurements made on a vehicle/payload combination in conjunction with a static test on the payload.

STRUCTURAL

79-1697
Direct Time Integration Methods in Nonlinear Structural Dynamics
C.A. Felippa and K.C. Park
Palo Alto Research Lab., Lockheed Missiles and Space Co., Inc., Palo Alto, CA, Rept. No. LMSC/D013361, 74 pp (Aug 1978)
AD-A060 410/8GA

Key Words: Dynamic structural analysis, Nonlinear theories

This paper reviews some recent developments in direct time integration methods for nonlinear structural dynamics. The developments pertain to the use of linear multistep difference operators in conjunction with the pseudo-force approach. The paper is organized into three main sections. An introductory section provides an overview of the transient response analysis problem. A section on computational aspects deals with the organization of the numerical calculations; this material is largely based on a recent detailed study of linear dynamic calculations. A section on integration methods highlights algorithmic aspects that impact the selection of integrator for nonlinear problems and discusses adaptive analysis features such as step-size control and implicit matrix scaling techniques. An appendix section outlines the functional orgainization of modular 'integration driving' software.

79-1698
Seismic Stability of Surface Hydel Power Station Substructure
P. Nandakumaran and S. Mukerjee
Dept. of Earthquake Engrg., Univ. of Roorkee, U.P., India, Symp. Earthquake Engrg., Oct 5-7, 1978, Univ. of Roorkee, Roorkee, India, pp 289-294, 4 figs, 3 tables, 5 refs

Key Words: Hydroelectric power plants, Seismic excitation

A stability analysis is carried out assuming the sliding wedge to be analogous to a block resting on a rough surface and supported by a spring. The resisting forces are considered in two parts: friction at the base of the raft, and passive resistance of the soil in front. Using the yield acceleration concept and by equating the maximum kinetic energy attained by the unit block to the strain energy stored in the passive soil spring; the actual displacement suffered by the unit block is obtained.

TURBOMACHINERY

79-1699
Aeroelasticity Research for Turbomachine Applications
S. Fleeter
Purdue Univ., West Lafayette, IN, J. Aircraft, 16 (5), pp 320-326 (May 1979) 9 figs, 1 table, 36 refs

Key Words: Turbomachinery, Aerodynamic loads, Fluid-induced excitation, Flutter, Forced vibration

The continuing demand for increased performance in turbine engine turbomachinery has aggravated dynamic problems in the various components, particularly the blading. These problems are generally classified into the categories of either flutter or forced response. Current research effort, coordinated between industry, government, and universities, is directed toward the development of phenomenologically founded approaches to these problems. Presented herein is an overview of this attack on aerodynamically induced vibrations in turbomachines.

79-1700

Telemetry for Turbomachinery

A. Adler
Acurex Corp., Mountain View, CA, Mech. Engr., pp 30-35 (Mar 1979) 6 figs, 1 ref

Key Words: Turbomachinery, Mechanical telemetry, Rotors, Testing techniques

This article looks at telemetry, its advantages and limitations, how to choose between telemetry and slip-rings, how to design a telemetry installation, and how to conduct an engine test. Forthcoming developments are reviewed.

AUTHOR INDEX

CALENDAR

SEPTEMBER 1979

21st Polish Solid Mechanics Conference, [Polish Academy of Sciences, Institute of Fundamental Technological Research] Poland ***(Dr. Marek Elzanowski, Institute of Fundamental Technological Research, Świętokrzyska 21, 00-049, Warsaw, Poland)***

9-14 **Petroleum Mechanical Engineering Conference** [ASME] Hyatt Regency, New Orleans, LA ***(ASME Hq.)***

10-12 **ASME Vibrations Conference,** [ASME] St. Louis, MO ***(ASME Hq.)***

10-13 **Off-Highway Meeting and Exposition** [SAE] MECCA, Milwaukee, WI ***(SAE Meeting Dept., 400 Commonwealth Dr., Warrendale, PA 15096)***

11-14 **INTER-NOISE 79,** [INCE] Warsaw, Poland ***(INTER-NOISE 79, IPPT PAN, ul. Świętokrzyska 21, 00-049 Warsaw, Poland)***

OCTOBER 1979

7-11 **Fall Meeting and Workshops,** [SESA] Mason, OH ***(SESA, 21 Bridge Square, P.O. Box 277, Saugatuck Sta., Westport, CT 06880 - Tel (203) 227-0829)***

16-18 **50th Shock and Vibration Symposium,** Colorado Springs, CO ***(H.C. Pusey, Director, The Shock and Vibration Information Center, Code 8404, Naval Research Lab., Washington, D.C. 20375 - Tel (202) 767-3306)***

16-18 **Joint Lubrication Conference,** [ASLE-ASME] Dayton, OH ***(ASME Hq.)***

17-19 **Stapp Car Crash Conference** [SAE] Hotel del Coronado, San Diego, CA ***(SAE Meeting Dept.)***

NOVEMBER 1979

4-6 **Diesel and Gas Engine Power Technical Conference,** San Antonio, TX ***(ASME Hq.)***

5-8 **Truck Meeting,** [SAE] Marriott, Ft. Wayne, IN ***(SAE Meeting Dept.)***

26-30 **Acoustical Society of America, Fall Meeting,** [ASA] Salt Lake City, UT ***(ASA Hq.)***

27-29 **8th Turbomachinery Symposium,** [Gas Turbine Labs., Texas A&M University] Houston, TX ***(Dr. M.P. Boyce, Gas Turbine Labs., Dept. of Mech. Engrg., Texas A&M University, College Station, TX 77843 - Tel (713)845-7417)***

DECEMBER 1979

Aerospace Meeting [SAE] Los Angeles, CA ***(SAE Meeting Dept.)***

2-7 **Winter Annual Meeting** [ASME] Statler Hilton, New York, NY ***(ASME Hq.)***

FEBRUARY 1980

26-29 **Congress & Exposition** [SAE] Cobo Hall, Detroit, MI ***(SAE Meeting Dept.)***

MARCH 1980

9-13 **25th Annual International Gas Turbine Conference and Exhibit** [ASME] New Orleans, LA ***(ASME Hq.)***

APRIL 1980

21-25 **Acoustical Society of America, Spring Meeting** [ASA] Atlanta, GA ***(ASA Hq.)***

MAY 1980

25-30 **Fourth SESA International Congress on Experimental Mechanics,** [SESA] The Copley Plaza, Boston, MA ***(SESA Hq.)***

JULY 1980

7-11 **Recent Advances in Structural Dynamics Symp.,** [Institute of Sound and Vibration Research] University of Southampton, Southampton, SO9 5NH, UK ***(Mrs. O.G. Hyde, ISVR Conference Secretary, The University, Southampton, SO9 5NH, UK - Tel (0703) 559122, Ext 2310)***

CALENDAR ACRONYM DEFINITIONS AND ADDRESSES OF SOCIETY HEADQUARTERS

AFIPS: American Federation of Information Processing Societies
210 Summit Ave., Montvale, NJ 07645

AGMA: American Gear Manufacturers Association
1330 Mass. Ave., N.W.
Washington, D.C.

AHS: American Helicopter Society
1325 18 St. N.W.
Washington, D.C. 20036

AIAA: American Institute of Aeronautics and Astronautics, 1290 Sixth Ave.
New York, NY 10019

AIChE: American Institute of Chemical Engineers
345 E. 47th St.
New York, NY 10017

AREA: American Railway Engineering Association
59 E. Van Buren St.
Chicago, IL 60605

AHS: American Helicopter Society
30 E. 42nd St.
New York, NY 10017

ARPA: Advanced Research Projects Agency

ASA: Acoustical Society of America
335 E. 45th St.
New York, NY 10017

ASCE: American Society of Civil Engineers
345 E. 45th St.
New York, NY 10017

ASME: American Society of Mechanical Engineers
345 E. 45th St.
New York, NY 10017

ASNT: American Society for Nondestructive Testing
914 Chicago Ave.
Evanston, IL 60202

ASQC: American Society for Quality Control
161 W. Wisconsin Ave.
Milwaukee, WI 53203

ASTM: American Society for Testing and Materials
1916 Race St.
Philadelphia, PA 19103

CCCAM: Chairman, c/o Dept. ME, Univ. Toronto, Toronto 5, Ontario, Canada

ICF: International Congress on Fracture
Tohoku Univ.
Sendai, Japan

IEEE: Institute of Electrical and Electronics Engineers
345 E. 47th St.
New York, NY 10017

IES: Institute of Environmental Sciences
940 E. Northwest Highway
Mt. Prospect, IL 60056

IFToMM: International Federation for Theory of Machines and Mechanisms, U.S. Council for TMM, c/o Univ. Mass., Dept. ME
Amherst, MA 01002

INCE: Institute of Noise Control Engineering
P.O. Box 3206, Arlington Branch
Poughkeepsie, NY 12603

ISA: Instrument Society of America
400 Stanwix St.
Pittsburgh, PA 15222

ONR: Office of Naval Research
Code 40084, Dept. Navy
Arlington, VA 22217

SAE: Society of Automotive Engineers
400 Commonwealth Drive
Warrendale, PA 15096

SEE: Society of Environmental Engineers
6 Conduit St.
London W1R 9TG, UK

SESA: Society for Experimental Stress Analysis
21 Bridge Sq.
Westport, CT 06880

SNAME: Society of Naval Architects and Marine Engineers, 74 Trinity Pl.
New York, NY 10006

SPE: Society of Petroleum Engineers
6200 N. Central Expressway
Dallas, TX 75206

SVIC: Shock and Vibration Information Center
Naval Research Lab., Code 8404
Washington, D.C. 20375

URSI-USNC: International Union of Radio Science - US National Committee c/o MIT Lincoln Lab., Lexington, MA 02173